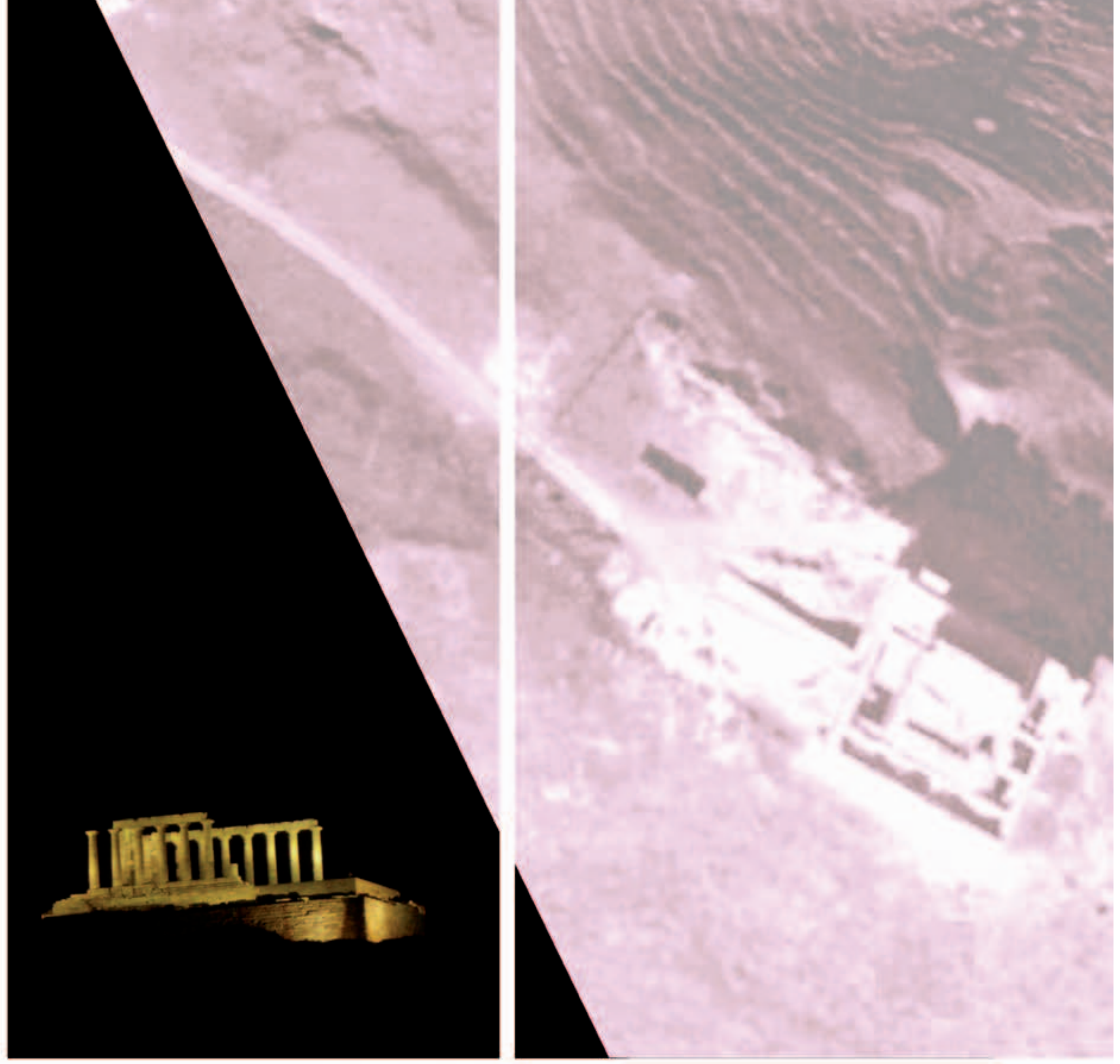
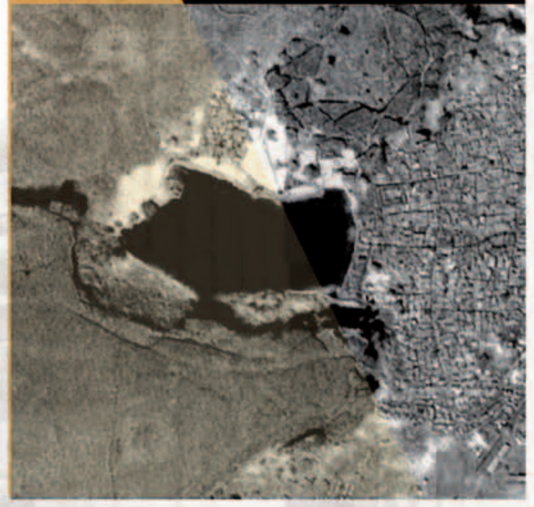
ARACNE





The book collects the contributions presented by 240 scientists coming from 25 countries, during the 1st International EARSeL Workshop on "Advances on Remote Sensing for Archaeology and Cultural Heritage Management", held in Rome on September 30 – October 4, 2008.
The result is a fascinating and rich variety of issues, applications and study cases of Remote Sensing, GIS and ICT for archaeological research, management of cultural resources, valorisation and documentation of historical sites and monuments.

ISBN 978-88-548-2030-2

euro 34,00

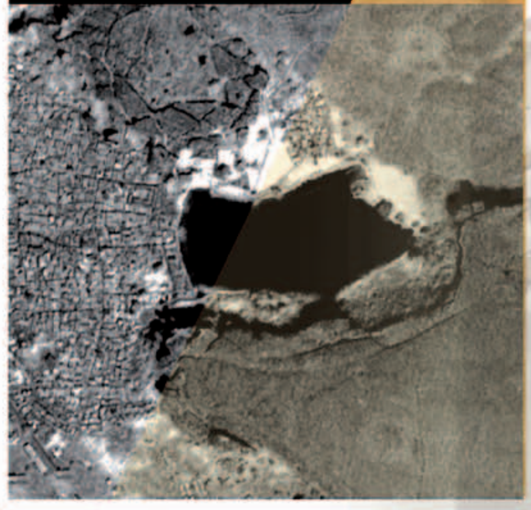
Lasaponara
Masini
editors

Remote Sensing for Archaeology and Cultural Heritage Management

ARACNE

Remote Sensing for Archaeology and Cultural Heritage Management

CD–Rom included



Rosa Lasaponara & Nicola Masini
editors

A10

402

Proceedings of the 1st International EARSeL Workshop
CNR, Rome, September 30 – October 4, 2008

Advances on Remote Sensing for Archaeology and Cultural Heritage Management

Edited by
Rosa Lasaponara
Nicola Masini

CD–Rom included

ARACNE

Published for :
EARSeL – European Association of Remote Sensing Laboratories
CNR – IMAA (Istituto di Metodologie di Analisi Ambientale)
CNR – IBAM (Istituto per i Beni Archeologici e Monumentali)

Cover design: Nicola Afflitto (IMAA–CNR)

Disclaimer: the Editors and the Publisher Aracne Editrice S.r.l. accept no responsibility for errors or omissions in the papers and shall not be liable for any damage to property or persons arising from the use of information contained herein.

Published and distributed by Aracne Editrice s.r.l. via Raffaele Garofalo, 133 A–B, 00173 Rome, Italy.
T. +39 (0)693781065, www.catalogoaracneeditrice.eu

Copyright © MMVIII
ARACNE editrice S.r.l.

ISBN 978–88–548–2030–2

No part of this book may be reproduced in any form, by print, photoprint, microfilm, microfiche, or any other means, without written permission from the publisher.

1st edition: September 2008

Table of contents

Preface

Rosa Lasaponara, Nicola Masini

Presentation

Francesco D'Andria

Vincenzo Cuomo

Acknowledgements

1. Satellite imagery for archaeology: data processing methods and study cases

1.1 Following O.G.S. Crawford: satellite images and field archaeology in Sudan 3
M. Drzewiecki, W. Raczkowski

1.2 The applicability of image processing techniques for archaeological exploration using space imagery: Talakadu - a case study 7
M.B. Rajani, S.K. Patra

1.3 Satellite-based archaeological research in the ancient territory of Hierapolis (Turkey) 11
R. Lasaponara, N. Masini, G. Scardozzi

1.4 Detection of burial mounds in high-resolution satellite images of agricultural land 17
Ø. Due Trier, A. Loska, S. Øyen Larsen, R. Solberg

1.5 A view on Greater Angkor: a multi-scalar approach for investigating the Khmer forests 23
A. Traviglia

1.6 Satellite remote sensing geoarchaeology of the ancient silver mine of Jabali, Yemen 27
J.-P. Deroin, F. Téreygeol, I. N.Al-Ganad,P. Benoit, J. Heckes

1.7 Data fusion techniques for supporting and improving satellite-based archaeological research 31
B. Aiazzi, S. Baronti, L. Alparone, R. Lasaponara, N. Masini

1.8 Vicus Costanziaci between land and sea: Remote Sensing applications for the detection of the lost islands in the Venetian Lagoon 37
A. Traviglia, D. Cottica, L. Fozzati

1.9 Stereoscopic view, extracting DEM and cartography for archaeological purposes from Ikonos stereo pair: a case from Hierapolis of Phrygia territory (Turkey) 41
G. Di Giacomo, I. Ditaranto, G. Scardozzi

2. Aerial archaeology: from the historical photographs to multispectral and hyperspectral imagery

2.1 The future of aerial archaeology (or are algorithms the answer?) 47
W.S. Hanson

2.2 Aerial Archaeology in Italy. Recent research and future developments 51
G. Ceraudo

2.3 Giacomo Boni: a pioneer of the archaeological aerial photography 55
L. Castrianni

2.4 Images of Conflict: an archival research of Great War air photos and overview of the main applications 59
B. Stichelbaut, J. Bourgeois

2.5 Aerial survey and ancient landscapes in Salento (southern Apulia). Combining advanced 63

technology and traditional methods
M. Sammarco

2.6 The “Via Traiana Project” 67
V. Ferrari

2.7 Lilybaeum reconstruction by remotely data 71
P. Merola, D. Guglietta, S. Sampietri, A. Allegroni, D. Guglietta, S. Sampietri, A. Allegrini

2.8 Airborne hyperspectral remote sensing as a tool for detecting buried archaeological structures: preliminary results for land cover in different contexts. 75
C. Bassani, R. M. Cavalli, S. Pascucci, S. Pignatti

2.9 Exploring the Edges of the Unseen: an Attempt to Digital Aerial UV Photography 79
G. *Verhoeven*

2.10 The combinatorial explosion: defining procedures to reduce data redundancy and to validate the results of processed hyperspectral images. 85
A. Traviglia

3. Active airborne and satellite sensors (lidar, SAR): data processing and applications

3.1 Satellite Systems devoted to Earth’s Remote Sensing: a tool for Archeological Applications 93
F. Vespe, G. Milillo, G. Lacicerchia

3.2 Hydrologic History of the Eastern Sahara from Imaging Radar: A Framework for Archaeological Exploration 97
Tom G. Farr, Ron G. Blom, Philippe Paillou

3.3 High resolution LiDAR for the recording of archaeological monuments & landscapes 99
A. Corns, R. Shaw

3.4 Ancient and modern: Combining different remote sensing techniques to interpret historic landscape 103
S. Crutchley

3.5 Hyperspectral and LIDAR data fusion applied to archaeological studies: the Aquileia site 107
P. Sterzai, F. Coren, N. Creati, M. Vellico, C. Pietrapertosa

3.6 GIS based processing of multiple source prospection data in landscape archaeology 113
S. Boos, H. Müller, S. Hornung, P. Jung

4. Sub-surface reconstruction based on GPR, magnetic and electrical tomography for archaeological research

4.1 The Role of Integrated Geophysical Survey Methods in the Assessment of Archaeological Landscapes: the case of Portus 121
K. Strutt, S. Keay

4.2 Integrated investigation to study and characterize the Archaeological site of P.zza d’Armi - Veio (Rome, Italy) 125
S. Piro, G. Bartoloni, V. Acconcia, S.T. Kortenaar

4.3 Novel tomographic based algorithms and processing strategies for multi-frequency antennas GPR measurement 131
F. Soldovieri, L. Orlando

4.4 A modelling/inverse-scattering approach to investigate the potential of GPR for the location of archaeological human remains 135
L. Nuzzo, T. M. Millington, N. J. Cassidy, J.K. Pringle

4.5 Comparing Inverse Scattering Algorithm and Imaging Standard Processing for GPR Data 139
R. Castaldo, M. Fedi, B. Garofalo, L. Crocco, F. Soldovieri, R. Persico

4.6 Analysing the velocity of ground-penetrating radar waves: a case study from Koekelare (Belgium) 143
L. Verdonck, D. Simpson, W. Cornelis, A. Plyson, J. Bourgeois

4.7 Preservation of archaeological patrimony through georadar study. The case of the Historical Center of the Merida City, Yucatán, Mexico 147
L. Barba, J. Ligorred, J. Blancas, A. Ortiz

4.8 Exploitation of a microwave tomographic approach for GPR data processing collected at historical buildings of Chania (Crete, Greece). 151
M. Bavusi, S. Piscitelli, F. Soldovieri, L. Crocco, G. Prisco, F. Vallianatos

4.9 3d High resolution ground penetrating radar (GPR): an application for evaluating the state of maintenance of the hypogeum structure in an urban area 155
G. Leucci, S. Negri

4.10 Integrated geophysical investigations at the Martyrium of Saint Philip, Hierapolis, Turkey 159
M. *T. Carrozzo, G. Leucci, S. Negri, L.Nuzzo*

4.11 Magnetic and Electrical integrated approach for the investigation of an archaeological site at Kassaneva-Devinu (Greece) 163
D. Chianese, B. Di Fiore

4.12 Application of Integrated Geophysical Prospection Techniques for Mapping Ancient Sikyon, Greece 169
B. Gourley, Y. Lolos, Apostolos Sarris

4.13 Quantification of buried slag volumes by using non-invasive geophysical methods 175
N. Florsch , M. Llubes, F. Téreygeol, A. Ghorbani, P. Roblet

4.14 On the application of near-surface temperature investigations for delineation of archaeological targets 179
L. V. Eppelbaum

4.15 Application of the Holographic Radar RASCAN to Cultural Heritage Inspection 185
L. Capineri, P. Falorni, G. Borgioli, T. Bechtel, S. Ivashov, A. Zhuravlev, M. Paradiso, G. Cartocci.

5. Integration of space/air borne and ground remote sensing techniques for archaeology and cultural heritage

5.1 World Heritage Sites in South Asia: Enhancing geophysical surveys with satellite imagery 191
A. Schmidt, R. Coningham

5.2 Ground-based, aerial and satellite remote sensing to investigate archaeological and palaeoenvironmental features: the study case of Tavoliere (Apulia, Italy) 195
M. Ciminale, D. Gallo, R. Lasaponara, N. Masini

5.3 Integration of remote sensing, geophysical surveys and archaeological excavation for the study of a medieval mound (Tuscany-Italy) 201
S. Campana, M. Dabas, L. Marasco, S. Piro, D. Zamuner

5.4 Using of VHR satellite data for potential digs localisation and their verification using geophysical methods 207
K. Pavelka, M.Bukovinský, J.Svatušková

5.5 Integrated remote sensing techniques for the detection of buried archaeological adobe structures: Preliminary results in Cahuachi (Peru) 213
N. Masini, E. Rizzo, R. Lasaponara, G. Orefici

5.6 Airborne and ground remote sensing for archaeological applications: landscapes and mines in Gargano area (Italy) 219
R. Salvini, F.M. Martino, A. Galiberti, M. Tarantini, F. Mantovani

5.7 Airborne and satellite Multispectral imagery at the Etruscan site of San Giovenale, Blera (Lazio) – Preliminary results 225
Y. Backe Forsberg , R. Holmgren, A. Lanorte, R. Lasaponara, N. Masini

5.8 Spatial Remote Sensing Archaeology and Network Connection Information Theory with Point Resource System 229
Sun Jianzhong

5.9 Field and Laboratory Investigations, An Alternative Tools, To Examine Damage Category Of 233

Monumental Sandstone at Arid Regions, Seti I Temple, Upper Egypt, case study
G. M. E. Kamh, R. Azzam

6. 3D visualization and Virtual reconstruction of landscape and sites

6.1 From remote sensing to 3D modelling and virtual reconstructions of the Iraqi archaeological sites: the case of Hatra 239
M. Cultraro; F. Gabellone; G. Scardozzi

6.2 Multi-scale geometry acquisition and visualization: issues and techniques 243
M. Callieri, M. Dellepiane, F. Ganovelli, R. Scopigno

6.3 Virtual Rome project: a web-based VR application on the archaeological landscape of Rome 247
S. Pescarin, L. Calori, M. Forte

6.4 Using digital photogrammetric restitution for the virtual reconstruction of the walls around the 'Titani' acropolis (Greece) 253
T. Nuttens, A. De Wulf, R. Goossens, C. Tytgat, D. Van Damme, D. Devriendt

6.5 Development of integrated 3D methods for the creation of a DVR-based knowledge platform 257
F. Gabellone, I. Ferrari, F. Giuri, M. Limoncelli

6.6 Computer Graphic Modelling at Portus: Analysis, Reconstruction and Representation of the Claudian and Trajanic Harbours 261
G.P. Earl, S.J. Keay, G.C. Beale

6.7 3D perspective views and their applications to Archaeology: A case study on the site of Badami 265
M.B. Rajani, S.K. Patra, Mamta Verma

7. Remote Sensing and GIS based method applications for Cultural Heritage Management and Documentation

7.1 NASA remote sensing applications for archaeology and cultural resources management. 271
M. J. Giardino

7.2 Archaeological heritage management through aerial photography and satellite imagery: the Uch Enmek park – Republic Altay, Russia 275
W. Gheyle, R. Goossens, A. De Wulf, E. P. Dvornikov, J. Bourgeois

7.3 Remote Sensing and GIS for Archaeological Site Selection: Indian Examples 281
Asis Bhattacharya

7.4 Practical use of multispectral satellite images in general Norwegian Cultural Heritage Management and focused Viking Age research. Experiences from South-Western Norway 285
O.Grøn, F.A.Stylegar, S.Palmér, S.Aase. P.Orlando, K.Esbensen, S. Kucheryavski

7.5 Comparative cluster analysis to localize emergencies in archaeology 289
E. S. Malinverni, G. Fangi

7.6 Usability of IKONOS images as a basis of data capture for the NascaGIS 293
C. Richter, B.Teichert

7.7 GIS-based archaeological analysis of large areas in the Peruvian Andes based on high resolution satellite imagery 297
M. Sauerbier, P. Fux & H. Eisenbeiss

7.8 Multitemporal study of obsidian exploitation from Melka Kunture (Ethiopia) trough digital aerial photogrammetry and multispectral stereo-IKONOS II 301
R. Salvini, M. C. Salvi, A. Cartocci, S. Kozciak, R. Gallotti, M. Piperno

7.9 Remote sensing and GIS data managing for archaeological maps: the case of Hierapolis of Phrygia (Turkey) 305
G. Scardozzi, A. Spanò

7.10 Integration of geomatics techniques for the digital documentation of heritage areas 309
S. Campana, M. Sordini, F. Remondino

7.11 Use of declassified panoramic satellite imagery for change detection in an area of archaeological interest 313

G. Bitelli, V. Alena Girelli, S. Neri, L. Vittuari

7.12 Multiple sensors and multi-resolution data for large scale mapping and artifacts documentation 317
F. Chiabrando, A. Spanò

7.13 Multi-scale Cultural Heritage survey: quick digital photogrammetric systems 321
P. Salonia, T. Leti Messina, A. Marcolongo, A. Pozzi, S. Scolastico

7.14 Contribution of Satellite imagery and DEMs to the Detection of Neolithic Settlements in Thessaly, Greece 325
D. Alexakis, A. Sarris, Th. Astaras , K. Albanakis, D. Oikonomidis

7.15 Kite Aerial Photography (KAP) as a tool for completing GIS models. Ptolemais (Libya) case study. 329
M. Bogacki, W. Małkowski, K. Misiewicz

7.16 Development and use of a 4D GIS to support the conservation of the Calakmul site (Mexico, World Heritage Programme) 333
M. van Ruymbeke, V. Tigny , E. De Badts , R. Garcia-Moreno & R. Billen

7.17 Integration between high resolution satellite images, GPS and Tablet PC with a new software for archaeological survey: the Ulixes system 339
G. Di Giacomo, G.P. Di Giacomo, G. Scardozzi

7.18 Multitemporal remote sensing data for the knowledge and the monitoring of the Iraqi archaeological sites 343
G. Scardozzi

7.19 GIS applications for recovery and management of historical-architectonic heritage: case study of Tursi-Rabatana medieval site (southern Italy) 347
M. Lazzari, M. Danese, N. Masini

7.20 Advanced Technologies for Archaeological Documentation: Technological and Educational Aspects 351
A. Cabuk, F. Alanyali, F. Ergincan, A. Deveci, U. Avdan, S.N. Cabuk

7.21 Cultural Heritage management in GIS: cataloguing of ancient marbles in Apulia (South Italy) 355
M. Delli Santi

7.22 Using GIS for storing and analysing information concerning the consequences of earthquakes in historical centres 359
F.T. Gizzi, M.R. Potenza, N. Masini

7.23 Basic Statistic Measures for IRT images analysis: a 'sample wall' taken from Matera Cathedral, 363
M. Danese, D. Sanseverino

8. Landscape archaeology and palaeo-environmental studies based on Remote sensing, GIS and ICT

8.1 Three-Dimensional Reconstruction of Prehistoric Landscapes for Multitemporal Static and Dynamic Geovisualization of the Goseck Ring Ditch 369
T. Richter, D. Thürkow, S. Scheuer C. Gläßer

8.2 Space-borne archaeology: reconstructing ancient landscapes and detecting subterranean construction features in Southern Dobrogea (Romania) 373
I. A Oltean, L. L. Abell

8.3 Remote sensing for recording past landscapes of the Mesopotamian alluvial plain 379
J. Walstra, V.M.A. Heyvaert, P. Verkinderen

8.4 Lost courses of River Sarasvati and spatial distribution of Harappan settlements – Observations based on multisensor satellite data 383
M.B.Rajani, A.S.Rajawat

8.5 The morpho-topographic and cartographic analysis using GIS and Remote Sensing techniques of the archaeological site Cornesti "Iarcuri", Timis County, Romania 387
D. Micle, M. Török-Oance, L. Măruia

8.6 Climate Change and Human Occupation of the Sahara 393
R. Blom, T. Farr, J. Feynman, P. Paillou, A. Ruzmaikin

8.7 Archaeological landscape of the Don River Delta: archaeology, remote sensing and GIS 397
G. Garbuzov, I. Tolochko

8.8 Irrigation is Forever: a study of the post-destruction movement of water across the ancient site of Sri Ksetra, Central Burma 401
J. Stargardt, G. Amable, B. Devereux

8.9 The Google public geoinformation resources as a new open tool of landscape archaeology 405
G. Garbuzov

8.10 Archaeological exploration in the Talakadu region along the bank of the Cauveri river, Karnataka, Southern India using multi-sensor satellite data and Geographic Information System (GIS) 409
M.B. Rajani, A.S. Rajawat, M.S. Krishna Murthy, J. Kamini, Srinivas Rao

9. International Archaeological missions as outstanding 'laboratories' of archaeological science

9.1 Planning the Archaeological Park of Chan Chan (Perù) by mean of satellite images, GIS and photogrammetry 415
F. Colosi, G. Fangi, R. Gabrielli, R. Orazi, A. Angelini, C.A. Bozzi

9.2 Image analysis and measurement applied to the archaeological materials from pyrgos (cyprus) 419
M. R. Belgiorno, A. Lentini

9.3 Hierapolis of Phrygia Project: integration of archaeological survey and remote sensing data 425
G. Scardozzi

9.4 New perspectives for archaeological research by satellite imagery in Cahuachi (Peru) 429
N. Masini , R. Lasaponara, R. Coluzzi, G. Orefici

Indices

Keyword index 437

Author index 441

Preface

In the last two decades, the increasing development of ground, aerial and space remote sensing techniques and the tremendous advancement of Information and Communication Technologies (ICT) have focused a great interest in the use of remote sensing and ICT for supporting cultural heritage applications. In particular, the improved spatial and spectral capability of active and passive sensors has opened new challenging prospective for the use of EO (Earth Observation) technologies not only for the investigation but also, for the management and valorisation as well as for the monitoring and preservation of cultural resources. Additional challenges to this field of research are related to the crucial importance of the integration of remote sensing with other traditional archaeological data sources, such as aerial photo, field surveys, trials, excavations and historical documentation. Such an integration requires great efforts aimed at creating a strong interaction among archaeologists, scientists and managers interested in using remote sensing and ICT for supporting cultural heritage applications. Moreover, the impact of the past human activity upon the environment is an important issue not only in the field of archaeology, but, also for botany, forestry, hydrology, soil and geo-science. Thus, the knowledge on ancient landscape and human settling provides invaluable information for better understanding human-environmental interaction, climate change, and Earth's system.

The continuous collaboration among scientists working in different fields of Cultural Heritage can contribute to take benefits from the new sensors, techniques and methodological approaches for a wide range of investigation and application fields. A constructive and complementary multidisciplinary approach can open a revolutionary scenario unthinkable several decades ago.

In this cultural framework, in 2007, representatives of two Italian research institutes (IMAA, and IBAM) of the National Council Research (CNR) created the EARSeL Special Interest Group (SIG) on Remote Sensing for Archaeology and Cultural Heritage (Re.Se.Ar.C.H.). The SIG was formally launched in June 2007 at the annual EARSeL Symposium held in Bozen. Since then, the group has tried to foster interaction among archaeologists, scientists and managers interested in using remote sensing data (from ground, aerial and satellite) and Information Technologies to improve traditional approach for archaeological investigation, protection and management of Cultural Heritage.

In the context of the EARSeL Re.se.Ar.C.H. activities we have been pleased to organize the 1st International Workshop "Advances in Remote Sensing for Archaeology and Cultural Heritage Management" .The event has been carried out with the patronage of UNESCO and MiBAC (Italian Ministry of Cultural Heritage and Activities), and the sponsorship of ESA, BELSPO, ASI, CNR, BNL and the private company Geocart srl.

During the four days of the workshop more than 100 papers will be presented and discussed by over 244 authors coming from 25 different countries. A fascinating and rich variety of issues, applications and study cases emerges from the papers.
The Proceeding book includes 93 papers divided in 9 sections which focus the following topics:

- Aerial archaeology from the historical photographs to multispectral and hyperspectral imagery.
- Data processing issues and new perspectives of use of active airborne data (lidar, SAR);
- Multi-scale satellite imagery processing aimed at identifying, observing and interpreting archaeological features for different surface characteristics;
- Detection and spatial reconstruction of sub-surface remains by using GPR, magnetic and electrical tomography
- Opportunities and limits in the integration of space/air borne and ground remote sensing techniques.
- 3D visualization and Virtual reconstruction of landscape and sites.
- Landscape archaeology and palaeo-environmental studies based on Remote sensing, GIS and ICT.
- The integrated use of RS, GIS and ICT, for the management of cultural and natural heritage, rescue archaeology.
- The role played by the international archaeological missions in the development of new methodologies and the encouraging a widespread use of the new technologies within the archaeological community.

Rosa Lasaponara

EARSeL Re.Se.Ar.C.H. SIG Chair

Nicola Masini
EARSeL Re.Se.Ar.C.H. SIG Co-Chair

Presentation

I would like to express my warm thanks to the organisers of the "Advances in remote sensing for Archaeology and Cultural Heritage and Management" International Workshop, promoted by the Italian National Research Council through IBAM – Institute for Archaeological and Monumental Heritage (Cultural Heritage Department) and IMAA – Institute for Environmental Analysis Methods (Earth and Environmental Department).

The fact that I have chosen to express my appreciation in this presentation has nothing conventional or ritual about it – because, among other reasons, these words are written in Hierapolis-Pamukkale in Turkey, where I am involved in managing the Italian Archaeological Mission. Here a complex project for the study and recovery of cultural heritage is being conducted in one of the most extraordinary archaeological sites in the Mediterranean, where the monuments of the ancient city are set in the natural context of white travertine formations.

As well as archaeologists and architects, traditional figures in a site that is most typical of classical archaeological contexts, Hierapolis is currently playing host to a multidisciplinary team of scholars. Their research makes constant use of Geographical Information Systems, geomatics, satellite images enhanced by orthographic projection, and GPR-assisted geophysical prospections; the marble decorations of the Roman theatre are being surveyed with manual laser scanners (Handyscan); the territory surrounding Hierapolis, with its farms, sanctuaries and aqueducts, is being revealed by traditional surveys, even in the most rugged terrain, where however the use of GPS technology enables precise positioning of the archaeological items.

IBAM researchers are playing an important role in these activities, characterised by real and extensive interaction between "humanistic" and scientific expertise, thereby re-establishing the unity of research, too often fragmented as a result of "academic" practices in which disciplinary boundaries serve merely to ensure the self-replication of groups, and have little to do with the need for scientific openness and innovation.

The *Atlas of Hierapolis*, edited by myself, Giuseppe Scardozzi (IBAM, CNR) and Antonia Spanò (Politecnico of Torino), and recently published by Ege Yayınları of Istanbul, is a concrete example of what a multidisciplinary strategy can contribute to the study of an ancient city and its surrounding territory.

In the Conference held in Rome on Remote Sensing, Nicola Masini made a fundamental contribution in both scientific and organisational terms. The variety of methods proposed, the broad participation of international research bodies and the application of technology to the study of cultural heritage in all countries (Perù, Yemen, India etc.) all served to fulfil the prospect of a

"Global Archaeology" encompassing all cultures of the planet. The participation of UNESCO was thus of great importance, since it can now avail itself of these technologies in order to promote the conservation of the world's natural and cultural heritage, increasingly threatened by uncontrolled development. Today, working to combat the forces that tend to annul cultural diversity, to prevent unauthorised excavations driven by the venal interests of the illegal market in works of art and to conserve historic landscapes involves the use of geophysical prospections, multispectral and hyperspectral sensors and satellites images; all of which are technologies that were originally developed for military purposes and subsequently transformed into tools for the study and safeguard of cultural heritage.

Lastly I would like to stress another positive contribution of this Convention, regarding the 3D Visualisation and Virtual reconstruction of landscape and sites. The Iraq Project, promoted by Roberto De Mattei and conducted by researchers from IBAM, is a good example of how the reconstruction of items that were damaged during conflict plays such an important role in the recovery of cultural heritage and the recognition of its true value. Technology must also contribute to the diffusion of knowledge to the wider public and raise public awareness in support of cultural heritage: the digital reconstruction of landscapes and monuments obliges researchers to step out of their "specialist" confines and illustrate the results of their labours.

Today, communication technologies represent the most innovative aspect of many scientific disciplines, and this is especially true of the Cultural Heritage sector, where there is a growing demand from the public, at the local community level, for education and the management of cultural heritage with a view to tourism. The Acts of the Conference take account of all these aspects and, in the variety of the many contributions, make up a fascinating and complex mosaic.

Francesco D'Andria
Director of IBAM – CNR

Hierapolis – Pamukkale (Turkey)
25 August 2008.

Firstly I want to thank Earsel that promoted this workshop and the Organizing Committee for the successful job they made.

This workshop is successful not only for the number of participants and the quality of talks but overall because it offered different scientific communities the chance to meet and to discuss actual achievements and future challenges and perspectives.

In my opinion new observational technologies can play a key role in the discovery, assessment, monitoring and management of cultural heritage. This workshop is the forum where researchers engaged in cultural heritage management and the ones engaged in earth observation meet each others both to present recent results and to put the basis of a tighter cooperation.

My personal background is mainly the development and use of earth observation techniques both satellite and airborne and ground based. In last years there was an exceptional improvement of our observing capability, that is based on the development both of new sensors and computing capabilities. By this way new frontiers of applications are opened and they will be further enlarged by new missions and sensors that have been scheduled or are going to be developed and will become operational in next decade.

In my opinion one the most challenging frontier of Earth Observation is the application of new observational techniques in the field of cultural heritage. The exploitation of these capabilities requires a common work to be performed by people involved in observing techniques with people dealing with archaeology and cultural heritage management.

This is one of the main reasons that make this workshop so interesting. This is an important stone along the road of a cooperation that has to be straightened and stabilized.

In my opinion it is necessary to give continuity to this workshop scheduling it at a fixed periodicity, so to enlarge the research community involved in the share different competences and experience in the field of cultural heritage management.

If such a decision will be assumed, just now IMAA-CNR feels engaged to support future workshops.

Vincenzo Cuomo
Director of IMAA – CNR

Acknowledgement

We want to thank the Italian Space Agency (ASI) for funding the publication of this book.

We are grateful to all of those whose help has permitted us to bring the Workshop on "*Advances for Archaeology and Cultural Heritage Management*" to a successful conclusion.
In particular we thank the European Space Agency(ESA) and the Belgian Science Policy (BELPO) for the sponsorship of the event.

Funding and logistic support were also provided by
CNR – Department of Cultural Heritage, BNL, Geocart srl – Potenza, Soprintendenza Archeologica di Roma, Soprintendenza per i Beni Archeologici di Ostia.

We are grateful to eveyone responsible for all the organization and arrangements : Nicola Afflitto, Annamaria Briuolo, Rocco Caivano, Armando Cinnella, Rossella Coluzzi, Salvatore Falconieri, Emanuele Festa, Antonio Lanorte, Margherita Santarsiere.

Organization

Patronage

Sponsors

1

Satellite imagery for archaeology: data processing methods and study cases

Following O.G.S. Crawford
satellite images and field archaeology in Sudan

M. Drzewiecki, W. Raczkowski

Institute of Prehistory, Adam Mickiewicz University, Poznań, 61-809, Poland, mario517@wp.pl, wlodekra@amu.edu.pl

Keywords: O.G.S. Crawford, Sudan, satellite images, field archaeology

ABSTRACT.

The Middle Nile Valley is rich in fortified settlement remains. In the region between Abu Hamed and Atbara they date from the time of the Meroe Kingdom (richly described by Herodotus) to the British–Egyptian condominium. One of the few who did try to examine these territories was O.G.S. Crawford whose reports fill two monumental works published in the 1950s (*Castles and churches of Middle Nile Region*; *Fung Kingdom of Sennar*) which are for many scholars the only source of data for this part of the world. Although aerial photography was Crawford's specialization he had no opportunities for this in Sudan although he underlined its necessity and usefulness in his publications.

More than 50 years has past and knowledge about the archaeology of this region has not changed much. One of the objectives of our project was to record the remains of fortresses which lie on both sides of the Nile. Documentation includes photo galleries, sketch maps and plans showing arrangements of fortresses, detailed descriptions of walls and the character of each fort's location. Due to administrative restrictions as well as a lack of access to light aircraft we were not able to follow Crawford's idea to carry out aerial survey there. Instead we decided to use the satellite images available on the Internet. A detailed interpretation of them within the fortresses' catchment areas allowed us to discover/identify plenty of archaeological sites (some of them described by Crawford but most not mentioned at all). We achieved a very good correlation between the results of the satellite image interpretations and field walking. The experience we already have allowed us to interpret better the features visible on the satellite images.

Our project shows the usefulness of satellite images in archaeological research in such difficult, barely accessible regions. The rapid economic development in Sudan in recent years raises a lot of new problems with the management and protection of archaeological heritage. Access to satellite images (and with better resolution at our disposal more sites may be identified) might be a good solution for all working in the management and protection of archaeological heritage there as well for an archaeologist carrying out 'pure' research. But it is important to note, based on our experience (and not only), that effective interpretation of satellite images needs archaeological knowledge of the area under review. It is necessary to study the results of previous archaeological surveys and excavations in particular. Also one needs some knowledge about the current farming practices of local communities which leave traces in the landscape.

1 INTRODUCTION

The Middle Nile valley is rich in fortified settlement remains. In the region between Abu Hamed and Atbara they date from the time of the Meroe Kingdom (richly described by e.g. Herodotus) to the British-Egyptian condominium. However, regardless of such archaeological resources this region has never been under close archaeological investigation. The first reports of well preserved fortresses, churches and vast cemeteries were made as early as in the 19th century (e.g. Caillaud, 1826), but these spectacular descriptions did not manage to raise more interest in the archaeology of the region. The first archaeologist who was seriously interested in the middle Nile river was O.G.S.Crawford. His initial visits to Sudan were connected to his involvement in excavations led by Sir Henry Wellcome in 1913–1914 (at sites in Jebel Moya and Abu Geili – Crawford 1955). His fascination with Sudan returned when he retired – and Crawford visited Sudan in 1950, in 1951–1952 he worked on a project financed by the British Academy (e.g. Arkell, 1959). He published two books dedicated to selected aspects of archaeology in Sudan: *Castles and Churches in the Middle Nile Region* (1953a) and *The Fung Kingdom of Sennar* (1951). His articles – *Field Archaeology of the Middle Nile Region* (1953b) and *Christian Nubia: a Review* (1947) – are likewise extremely valuable. Crawford's work, in a systematic way, presented the archaeology of the Middle Nile region, particularly sites dating from the 'Christian' period and the Fung Kingdom.

2 O.G.S. CRAWFORD'S FIELD ARCHAEOLOGY

O.G.S. Crawford was never a conventional archaeologist for whom archaeological excavations were one of the most important stages of the investigation. From the start of his professional career he emphasised the need to develop *field archaeology*. Such an approach in the first half of the 20th century was understood as study of archaeological sites though it did not include excavations (Daniel, 1978). The study of archaeological sites was supposed to be based on the search for and discovery of a site, followed by in-depth documentation, measurements, sketches and mapping. Detailed maps of sites were one of the most important achievements of British *field archaeology*. Various methods were introduced into the study of sites e.g., phosphorus, resistivity method and ground penetrating radar and, in the 20th century, aerial photography. Photographs provided very precise information regarding the spatial structure of a site, its location and environmental context. A very important aspect of *field archaeology* was the fact that the methods were complementary, many different methods together gave a better overall picture of the site.

O.G.S. Crawford's experience in *field archaeology* started at the beginning of the 20th century. Hikes and bicycle tours across Salisbury Plain in the search for archaeological sites and their recording as one *field archaeology method* led Crawford to consider the difficulties and bonuses of this method of field prospection. He believed that for archaeological analysis the location of a site is especially important, as is its precise description and identification of its spatial structure. In the realisation of his research project in Sudan in 1951–1952 he decided to use this method in order to, in a relatively short period of time, get as much complete information about the sites as possible. Crawford also wanted to show that the application of this method could bring good results there, as in Great Britain (Crawford, 1953b). He also suggested ways to extended the range of research tools in Sudanese archaeology in contrast to the dominant model based mainly on excavations.

The publication of Crawford's research results has enabled his method to be refined. In Sudan Crawford travelled on both banks of the Nile visiting numerous sites. An important element in his work was interviews with local communities which gathered a lot of information. The foundation of his documentation was a detailed description which contained information about recorded artefacts as well as the geological-geomorphic conditions. He also analysed natural processes which occurred in the past and therefore affected the preservation of a particular site. The chronology of archaeological material was also recorded. Detailed sketches/plans and photographs of a site were likewise a vital element in the documentation. Thanks to this material it is now possible to locate these sites in the field (Crawford did not have suitable maps at his disposal), to review their current condition and ascertain the factors which affected a site. At many sites Crawford mentioned (e.g. Crawford, 1953a) that the descriptions would have been more precise he had appropriate aerial photographs to his disposal.

O.G.S. Crawford did not utilise the whole range of methods that *field archaeology* actually encompasses in his project. This is due to two reasons. Firstly, it was impossible to incorporate all methods, ie. aerial survey. Secondly, his project lasted only a short period (11.12.1951–3.03.1952). We can suppose that the first survey of the terrain could have become, in time, the basis for the realisation of further, more detailed projects. As history shows no detailed archaeological surveys in the area were undertaken, and any further publications (e.g. Edwards & El-Amin, 2000; Wiewióra, 2007) were based on data and material published by Crawford.

3 FOLLOWING O.G.S. CRAWFORD

O.G.S. Crawford's approach to archaeological survey and his findings from the middle of the 20th century became the inspiration for the project entitled *Fortresses of Sudan: following O.G.S. Crawford* (http://knsa.archeo.edu.pl/sudan). The aim of the project was to ascertain the current state of the fortresses which dated from the Christian period and to record archaeological sites in their catchment areas. In following Crawford's footsteps various techniques were used: the land was surveyed using GPS and Laser Distance Meter, photographic documentation was made, descriptions recorded and interviews with local communities were carried out. The plan of the project included aerial photography. However, due to numerous organizational and financial problems aerial reconnaissance was not accomplished. Therefore, as Crawford, neither did we have aerial photographs at our disposal. In an effort to fill this gap we decided to investigate the potential of the satellite images available on Google Earth.

4 POTENTIAL OF SATELLITE IMAGES FOR FIELD ARCHAEOLOGY IN SUDAN

Satellite images have been used in archaeology since the 1970s (e.g. Ebert, 1989). However, poor image resolution limited their use in this field whilst the satellite images currently available show the Earth's surface in much higher resolution. Their usefulness in archaeology likewise is increasing all the time.

In his analysis of the current application of satellite images in archaeology Rog Palmer proposed the distinction of two models of action. The first is connected with an in-depth computer analysis of the data which uses tools such as datafusion, edge detection, edge thresholding, edge thining, line extraction etc., to characterise individual pixels. The appropriate procedures permit an objective interpretation of archaeological resources in the context of their environment. The second model is based on experience gathered so far aerial photography interpretation and is limited to looking at the satellite image of the Earth's surface, in the same way one would view an ordinary aerial photograph.

The first model requires sophisticated knowledge in the field of computer analysis of data recorded via particular sensors and the appropriate software. It is quite difficult then to see how it could be used by the majority of archaeologists. The second model however requires archaeological knowledge of the chosen region and a certain level of experience of photograph interpretation. It was due to this perspective that the second model was used in our project.

Before the field walking stage of the project satellite images of selected forts and their catchments which were available on Google Earth were analysed. In this way we were able to identify various archaeological sites including: burial mounds, cemeteries, the stone foundations of buildings and numerous traces connected to current farming practices (the remains of irrigation systems, areas where harvested crops could be dried, kraal for livestock etc.), roads.

5 PRELIMINARY RESULTS OF THE PROJECT

In February 2008 within the framework of the project selected fortresses from the 'Christian' period with numerous signs of equally intensive use later were investigated. 12 fortified architectonic features were chosen (figure 1). Analysis of satellite images beforehand enabled their fast identification in the field (in Sudan access to detailed maps is still a problem). Measurements were made as were detailed descriptions and photographical documentation, beds of raw materials used in the construction of the fortresses were identified, information acquired earlier was compared to the current situation, interviews with local communities were carried out and questions were asked on how the sites were viewed in contemporary culture. The comparison of earlier information on the forts and their current state enabled the determination of quite obvious physical deterioration and not only. Worth noting is the fact that Crawford's documentation is, to a large extent, still relevant (even allowing for the destruction suffered over the last 50 years), this is not true of plans which were made later.

As mentioned earlier, in the preparatory stage, on the basis of satellite imagery, we identified approximately 100 points as potential archaeological sites within the catchment areas of the selected fortresses. As we knew their exact location (having the satellite images and geographical coordinates instead of maps) verification in the field was made possible. The results of this procedure were startlingly positive, as the majority of the points did turn out to be traces of past human activity (figures 2, 3). Part of the 'archaeological sites' visible on the satellite images turned out to be traces of current farming practices in the zone bordering the desert. Of the sites described by Crawford (not including the forts) only part were verified in the field – the remainder had been destroyed (e.g. the cemetery in El Koro).

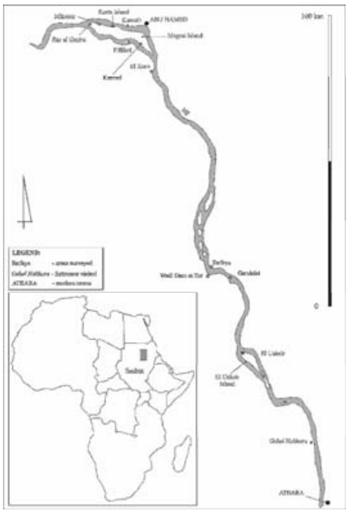
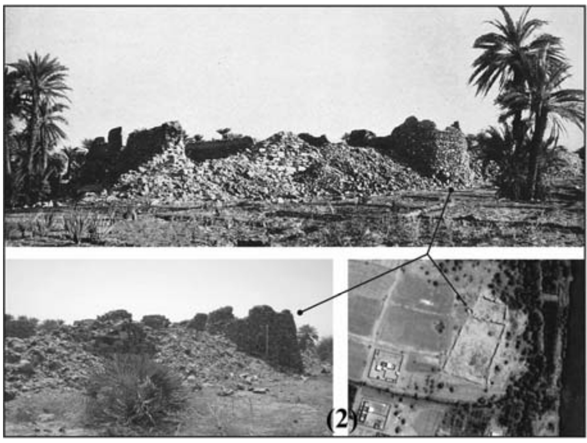


Figure 1. Map of Middle Nile Valley between Abu Hamed and Atbara – the project area

6 CONCLUSIONS

The results of the project so far have enabled many different scientific conclusions and assumptions to be made. From the perspective of the application of the method used by Crawford at the start of the 1950s we can say that it is still extremely useful under Sudanese conditions and permits further investigation into past Sudanese landscapes. By enriching the method with high resolution satellite imagery it is possible that change will occur in Sudanese archaeology. This particularly concerns speedy recognition of archaeological resources in regions under threat from planned investment. We observed many examples where the construction of vast irrigation canals cutting across the desert resulted in the destruction of many archaeological sites (mainly cemeteries). Currently under final review is the proposed construction of a dam near the 4th cataract. Shortly, a vast area of the Middle Nile Valley will be flooded. Thousands of small archaeological sites, which are not under close archaeological investigation will be destroyed without any, even basic, documentation being made. The reason for this is the short time left for archaeological action and the attitude of the local people (of the Manasir tribe) towards all activities related to the construction of the dam. As our experience gained during the project shows, by using satellite imagery with a good level of resolution (at least slightly better than that available on Google Earth) it is possible to quickly record traces of the past which are soon to be totally destroyed.



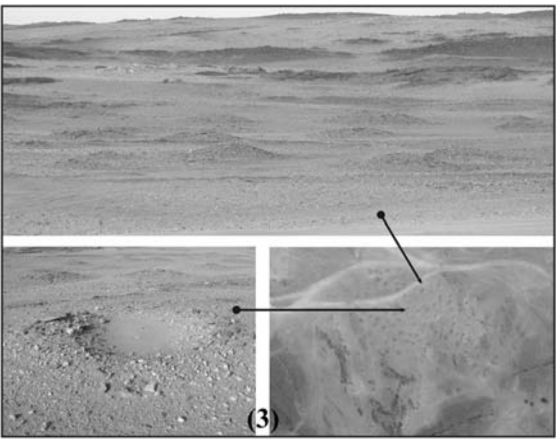


Figure 2 (left). Fortress at El Koro. Top: north–west corner (Photo: O.G.S. Crawford, 1952); bottom left: western tower (Photo: Ł. Banaszek, 2008); bottom right: satellite image, 2003 (© Google Earth). Figure 3(right). Cemetery at Wadi Dam et Tor. Top: view from the North (Photo: W. Rączkowski, 2008); bottom left: robbed grave (Photo: W. Rączkowski, 2008); bottom right: satellite image of a site, 2003 (© Google Earth)

7 REFERENCES

Arkell, A.J. 1959. O. G. S. Crawford, 1886–1957, *Kush*, 7: 232–235.

Caillaiud, F. 1826. *Voyage a Méroé, au Fleuve Blanc*. Paryż, L'Imprimerie Royale.

Crawford, O.G.S. 1947. Christian Nubia: a Review, *Antiquity*, 21: 10–15.

Crawford, O.G.S. 1951. *The Fung Kingdom of Sennar.* Gloucester, J. Bellows Ltd.

Crawford, O.G.S. 1953a. *Castles and Churches in the Middle Nile Region*. Khartoum, Commissioner for Archaeology (Sudan Antiquities Service, Occasional Papers, No 2).

Crawford, O.G.S. 1953b. Field Archaeology of the Middle Nile Region, *Kush*, 1: 1–29.

Crawford, O.G.S. 1955. *Said And Done*. London, The Trinity Press.

Daniel, G. 1978. *A Hundred and Fifty Years of Archaeology*. London, Duckworth.

Ebert, J.I. 1989. Techniques, Methods and Theoretical Goals in American Archaeological Remote Sensing: 'Predictive Modelling' as an Example, in Kennedy D., *Into the Sun: essays in air photography in archaeology in honour of Derrick Riley*, Sheffield, J.R. Collis Publications, 86–101.

Edwards, D.N., El-Amin, Y.M. 2000. Archaeological Survey in the Fifth Cataract Region, *Sudan and Nubia*, 4: 44–50.

Wiewióra M. 2007. *Architektura obronna w Nubii od V do XVI wieku.* Toruń, Wydawnictwo Uniwersytetu Mikołaja Kopernika.

The applicability of image processing techniques for archaeological exploration using space imagery: Talakadu - a case study

M.B. Rajani[1], S.K. Patra[2]
1 *National Institute of Advanced Studies (NIAS), Indian Institute of Science Campus, Bangalore 560 012, India, rajanihf@gmail.com*
2 *Advanced Data Processing Research Institute (ADRIN), 203, Akbar Road, Tarbund, Manovikasnagar Post, Secundrabad 500 009, India, patra.sumant@gmail.com*

Key words: Image processing techniques, archaeology, Talakadu site, image registration.

ABSTRACT: In the present work images taken from space platform were acquired to analyze Talakadu (an archaeological site in Karnataka, India) area and identify linear features and geometrical shapes that are not natural and therefore might indicate potential locations for archaeological exploration. The peculiar geographical configuration of the area has made the greater part of an old township completely buried under wind blown sand from the river Kaveri that skirts the west of Talakadu. Towards carrying out analysis in spatial, spectral and temporal domains, space imagery from Landsat Thematic Mapper, Multispectral images from LISS-IV sensor of Indian Remote Sensing Satellite (IRS) series and high resolution images from IRS CARTOSAT1 were used. Several image-processing algorithms were employed to evaluate their efficacy to identify linear features and geometrical shapes that might indicate presence of buried remains. These include edge enhancements, detection and thresholding, as well as change detection studies using Principal Component Analysis and change vector analysis. These analyses were conducted after subjecting all the imageries to a common reference image through automated registration using non-linear methods with sub pixel accuracy. This work presents the results of our investigations. Our preliminary analysis indicates at least four likely locations for further archaeological exploration, thus suggesting a new approach in the light of the methodology available.

1 INTRODUCTION

Archaeological sites often exist in ruins. It is very difficult to get an overall idea of their layout from ground level. Subsurface archaeological features manifest as linear and other geometric shapes through vegetation or soil marks on the surface. The ability to view an area from aerial and space platforms has presented the opportunity to observe a site in the context of its surrounding. This allows one to relate anomalous linear and geometric features scattered around with respect to the known features of the site. These are very conspicuous when seen from above and are hardly recognizable while traversing at ground level. The first step for conducting research over archaeological sites using images from space platform is to decide the nature of images to be acquired for investigation, such as spatial, spectral and temporal resolution. The choice of spatial resolution depends on the objective of the project, i.e. what scale of objects is intended to be seen. Choice of spectral resolution depends on the nature of land cover on and around the site. The temporal component is dictated by the needs of change detection as part of the study. Anomalous marks on surface are very subtle; any minor differences in the surface could either make the features appear enhanced and more conspicuous or conversely less noticeable. Differences in land cover occur due to seasonal changes in vegetation or, changes occurring over a period of time. Archaeological features can be revealed during dry season or droughts as areas holding more moisture as a result of subsurface structures like canal, ditch or moat would be enhanced. Similarly in times of high moisture content, in which case negative crop marks caused by subsurface structures, like foundation or buried walls, become conspicuous due to lack of moisture (Wilson, 2000). Where as the nature of the study area should ideally be considered for the choice of observation dates and resolution, in practice it is rather difficult to decide the ideal season during which the characteristics of surface would be most revealing.

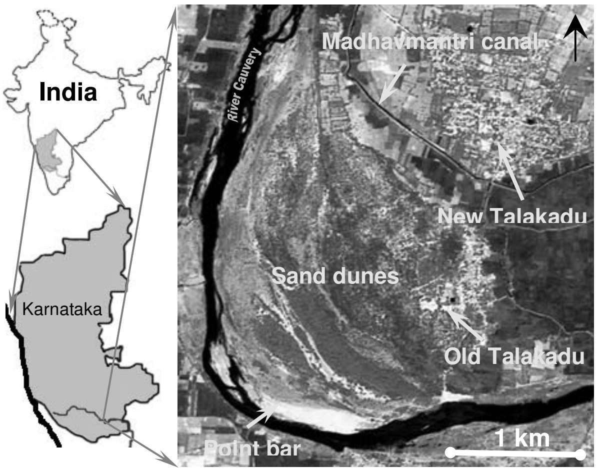


Figure1. Talakadu area (Karnataka, India) as seen on Resourcesat-1 LISS-IV FCC Imagery of March 24, 2005

In the spectral domain there is hardly any doubt regarding the usefulness of multi spectral data, especially with a combination of NIR region because most anomalies present themselves as vegetation marks (Rajani, 2007), though further longer wave lengths (SWIR, TIR) are yet to be exploited. In spatial domain different spatial resolutions can be used to identify features of different scales. High resolution ~1m or better shows details of structures whereas coarser resolution of 5.8m or 23.5m shows feature that are part of larger landscape, often not perceived in higher resolution (Joseph, 2005; Gibson *et al.*, 2000).

2 DATA AND METHODS

For the present study on Talakadu a combination of mutli-spatial, multi-spectral and multi temporal data from multi sensors has been used. Talakadu is a historical site on the bank of river Kaveri in southern India (*figure 1)*, with evidence of human presence in parts since the Megalithic period. This site was the capital of the Ganga dynasty in the 5th century, subsequently was inhabited by four other kingdoms in the following ten centuries. Influences at different periods are reflected in the cultural remains such as architecture and artefacts found on the site. It is situated very close to the inner curve of a sharp bend in the river course. The peculiar configuration of the river flow and also the dam to the north of Talakadu, jointly have accumulated large amounts of river sand on the bend. The barrage was first built in 14th century by Madhavamantri, a local minister. The annual south-west monsoon wind pattern has swept the fine sand over to the site on the north-eastern side in the last few centuries burying it under several feet of dunes. Over this there is a vegetative cover firstly as a result of a deliberate human effort in early 20th century to arrest the movement of wind-blown sand by planting eucalyptus and casuarina trees, secondly by natural under-growth of shrubs and weeds. Approximate area of sand cover is about 4.5 km sq of which less than 1% have been excavated (Sivaramkrishna, 2005; Devaraj et al., 1996; Narasinhachar, 1950). Therefore the site is pristine as far as its potential for archaeological study is concerned.

It is quite clear from historical and archaeological information that there is a whole township buried under the sand. The present study has been initiated to identify patterns that might suggest the layout of the township and hence potential locations for exploration and excavation. High resolution PAN data of Cartosat-1 (2.5m) was merged with IRS-LISS-IV multispectral data (5.8m) and was used to identify the known structures such as temples. IRS-LISS-IV multispectral data of three dates at around the same season was analyzed to study the recent changes in the area. Landsat-5 TM images for four dates spanning over last 20 years with around 4-5 year interval between each was used to study geomorphological and land cover changes in the overall site in the last two decades. Excavations in 7-8 small pockets of few sq. m. each have been conducted by the Karnataka state Department of Archaeology. To recognize these locations and integrate the information gained from Excavation GPS was used. Table 1 shows the details of all the data used for this study.

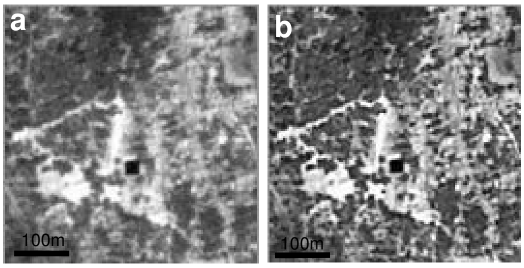
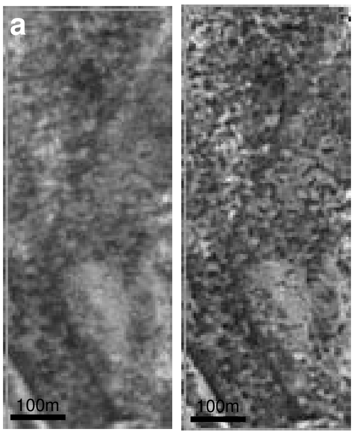


Figure 2. The improvement in quality with respect to cartographic features and color fidelity: (a) original image and (b) restored image. BBR is 0.3 pixels.



In conducting this study the most crucial aspect was to prepare all the acquired data by bringing them to a single reference frame by sub-pixel registration and improving their quality. The multi-resolution, multi-temporal and multi-sensor data are analyzed, where each image is different with respect to geometry and radiometry. Different sensors have their inherent arrangement of modules like optics and image gathering devices. For an example, IRS-P6 LISS-IV acquires multispectral images with a time delay of a few seconds. This arrangement creates a band to band misregistration and the entire three bands (green, red and near-infrared) do not co-register. This demands a sophisticated band to band registration (BBR) to sub-pixel accuracy to have good colour fidelity. Moreover, noise in an image hampers image processing to its optimum.

The following three methods were applied for improving data quality: BBR wherever required; Image restoration to improve the modulation transfer function; noise reduction. An automatic and specialized tool developed in ADRIN was used to address the issue of BBR, where match points are found through mutual information (MI) and images are transformed locally using radial basis functions called thin plate splines (TPS). We achieved an RMS error of 0.3 pixels for the data used. Image Restoration refers to removal or minimization of known degradations in an image. The objective of image restoration is to make an estimate of point spread function (PSF) and do an inverse filtering. These algorithms distinguish themselves from image enhancement methods in that they are based on models for the degrading process. The image restoration methods fall under the class of linear spatially invariant restoration filters. Wiener filter has a parameter called noise-to-signal power density ratio, which can be changed for varying degrees of image restoration. Harder restoration increases noise, which should be followed by noise smoothing operators. The quality improvement of the image is achieved through a MAP (Maximum a posteriori) estimates with signal and noise models as MRF and Gaussian respectively. *Figure 2* shows the result of image restoration and noise removal filter indicating overall image quality improvement.

Table 1. List of data used for the study

Satellites	**Sensor**	**Spectral bands** (µm)	**Spatial** (m)	**Swath** (km)	**Radiometry** (bits)	**Dates**
Resourcesat-1	LISS IV	0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR)	5.8	24	10 (7)	24.03.2005 12.02.2006 23.03.2007
	LISS III	0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR) 1.55-1.70 (SWIR)	23.5	141	7	27.02.2006
Cartosat-1	PAN	0.50-0.85	2.5	30	10	12.01.2008
Landsat-5	TM	0.45 - 0.52 (B) 0.52 - 0.60 (G) 0.63 - 0.69 (R) 0.76 - 0.90 (NIR) 1.55 - 1.75 (SWIR) 10.4 - 12.4 (Thermal) 2.08 - 2.35 (SWIR)	30 (multi-spectral) 120 (Thermal)	185	8	11.04.1989 05.03.1993 16.03.1997 23.02.2001

One of the basic image processing operations in remote sensing is image registration. It is the process of overlaying two or more images of the same scene taken at different times or from different viewpoints by the same or different sensors for the study of change detection and information fusion, for which confidence of only sub pixel level error is to be achieved. Satellite images acquired at different times with different acquisition geometry will pose certain variations with respect to geometry in scale, orientation, translation, relief displacements, and shadow due to solar angle. The first three factors can be corrected systematically by global transformations on any widely used software like ENVI or ERDAS. Discrepancies due to variations in relief cannot be accounted by global transformations. A finer registration process is needed to include the last two factors. This is achieved through a framework of image processing operations built in ADRIN.

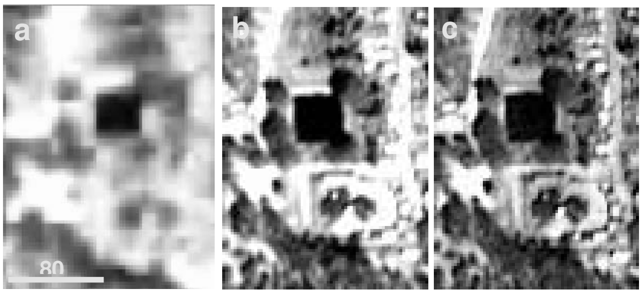


Figure 3. (a) LISS-IV 23.03.2007, 5.8m, (b) Cartosat1 PAN, 2.5m, (c) Cartosat1+ LISS-IV Pansharpened, 2.5m

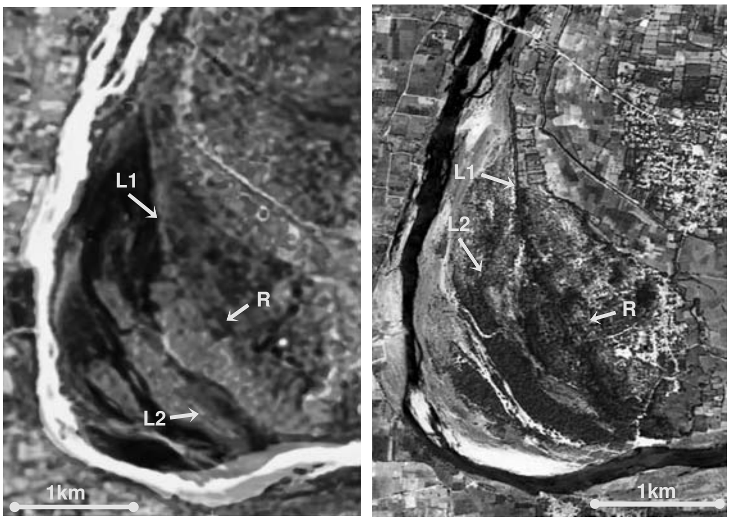


Figure 4. Left: the 1st PCs of three Landsat-5 TM data of 1993, 89 and 97 projected as RGB respectively. Right: the 1st PCs of IRS Liss4 data of 2005-07 are projected as RGB respectively.

The IRS LISS-IV 23.03.2007 data was taken as the reference image and was georefrenced with ground surveyed information through maps and further rectified by GPS survey. The other two IRS LISS4 data was then registered on to the reference image. Landsat-5 TM (30m) images of four dates, were resampled to 5.8m and registered to the reference image. The merged (Pansharpened) high resolution Cartosat-1 data was also registered to the reference image. Improved quality and correspondence established data sets are illustrated in figure *3*.

The images were individually analyzed. All observable linear and geometric features were extracted and separate shape files were made for each kind of feature, for each date. By viewing these shapefiles as thematic layers, temporal changes were analyzed. Features indicating modern activity such as roads, paths, buildings were separated and eliminated. Remaining features for which direct explanation was not evident were chosen for further investigation. Edge enhancements and thresholding was applied by selecting small areas to enhance specific features. Principle Components of Landsat TM was generated for each data. Principal components of IRS LISS-IV also was generated, some results are illustrated in figure 4. All these methods enhanced the features in the images and collective from all these few features have been identified (see figure *5*) for further exploration on ground.

3 CONCLUSIONS

By analyzing the remote sensing data, the present study has identified some features for further archaeological exploration (see figure *5*). Feature marked as L1 is thought to be an old canal that drew water from the dam to the township of old Talakadu, which is now completely buried in sand. Similarly L2 is conjectured to be a bund or fortification, R seems to be a large rectangular feature which might have been a reservoir especially as it is aligned at the end of L1 and VP which is the straight patch of vegetation suggests a high moisture content in that area compared to the surrounding.

In certain seasons the archaeological signatures can be more evident on satellite images through direct and indirect inferences, therefore temporal study of the area in different seasons and different epochs over a few decades can reveal extraordinary information. For analyzing temporal data, data preparation is a Herculean task which involves image registration, image restoration and image processing. This study suggests using space borne images of coarse to fine resolution and a new approach in the method of archaeological survey. By using temporal data of many satellites, this study has identified some features in Talakadu area, and these have been conveyed to the Department of Archaeology, Karnataka, for exploration.

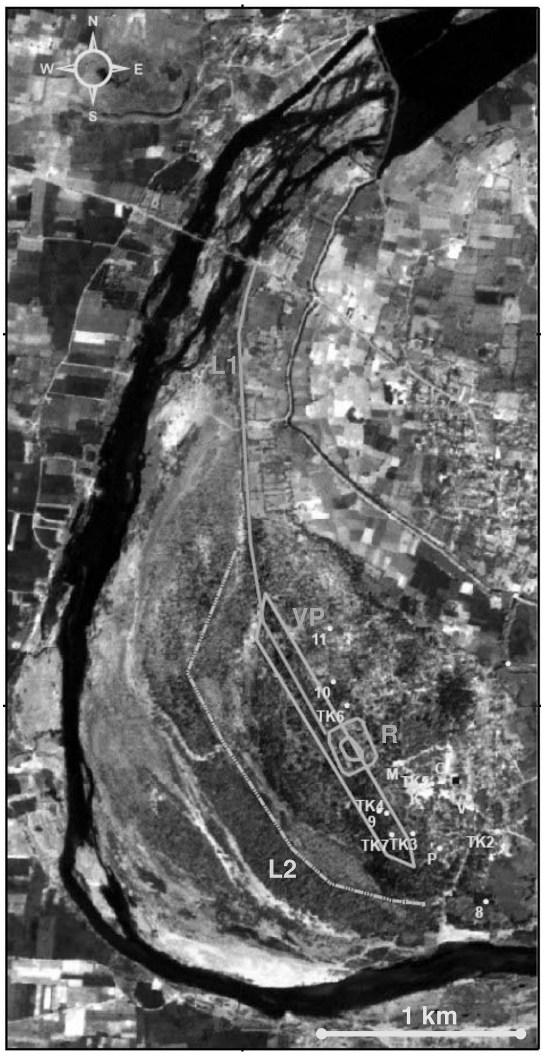


Figure 5. Features extracted from multi sensor RS data suggested for further archaeological

4 REFERENCES

Devaraj, D.V., Narasinha Murthy, A.V., Krishna Murthy, M.S., Swamy 1996. *Excavations at Talakaḍ*, Directorate of Archaeology and Museums, Mysore.

Gibson, P.J., Power, C. H. 2000. *Introductory Remote Sensing: Digital image processing and applications*. Routledge, London.

Joseph, G. 2005. *Fundamentals of remote sensing* University Press, Hyderabad, India.

Narasinhachar, L., 1950. *A guide to Talakad*, Government of Mysore, pp.1-20.

Rajani, M.B. 2007. Bangalore from above: an archaeological overview, *Current Science*, 93(10): 1352-1353.

Sivaramkrishna, S. 2005. *The curse of Talakad*, Rupa & Co., New Delhi.

Wilson, D.R. 2000. *Air photo interpretation for archaeologists*, Tempus, Gloucestershire, UK.

ACKNOWLEDGEMENTS:

We thank Dr. K. Kasturirangan, Director, NIAS and Dr. R. Krishnan, Director, ADRIN, for their overall guidance, Institutional support and encouragement in carrying out the present study. We thank Prof. B.V. Sreekantan and Prof. M.S. Krishna Murthy at NIAS for useful discussions.

Satellite-based archaeological research in the ancient territory of Hierapolis (Turkey)

R. Lasaponara[1], N. Masini[2], G. Scardozzi[3]

1 CNR- IMAA, C.da S.Loja – 85050 Tito Scalo (PZ), Italy. E-mail: lasaponara@imaa.cnr.it
2 CNR IBAM, C.da S. Loja 85050 Tito Scalo (PZ), Italy. E-mail: n.masini@ibam.cnr.it
3 CNR IBAM, Strada per Monteroni c/o Campus Universitario, Lecce, Italy. E-mail: g.scardozzi@ibam.cnr.it

ABSTRACT.

The ancient territory of Hierapolis (Turkey) has been investigated by using satellite QuickBird multispectral and panchromatic imagery for searching unknown potential archaeological remains. Principal Component Analysis and spectral indices were computed in order to enhance archaeological marks and make their identification easier. Results from the performed analysis allowed us to discover a number of potential archaeological remains that were verified by and carefully analyzed by field survey. In this paper, we focused on sites belonging to the Hellenistic to the Byzantine age. Relating to this period, several rural settlements were found. On the ground the visible remains of these ancient farms were sometimes negligible, but the processing of the satellite images highlighted the traces of buried walls. In this paper one of these rural settlements dating back from the early Imperial Roman and the proto-Byzantine age has been focused. External perimeter and structures of the ancient buried edifice were successfully identified and spatially characterized by Quickbird images.

Keywords: Satellite Remote sensing, archaeology, PCA, spectral index, Hierapolis, Turkey.

1 INTRODUCTION

Satellite QuickBird (QB) images have been used for finding traces of past human activity in the ancient territory of Hierapolis (Turkey). This is one of the most important archaeological sites in Turkey, and in 1988 it was inscribed in the World Heritage List. Although over the years the archaeological site of Hierapolis has been excavated, restored and well documented, up to now the territory around the ancient urban area is still largely unknown. The goal of the current research project, still in progress, is to search the area neighbouring Hierapolis believed to have been under the control of the city for a long time and, therefore, expected to be very rich in archaeological remains. To cope with the research project needs, QB panchromatic and multispectral satellite imagery were used for identifying unknown potential archaeological remains.

2 RESEARCH AREA

The investigation was performed in a significant test area located in the ancient territory of Hierapolis of Phrygia situated near Pamukkale and Denizli about 200 km East of Izmir (fig.1a). Archaeological investigation performed over the years identified four subsequent steps of the historical development of the city: (i) from its foundation in the 3rd century BC until the devastating earthquake in 60 AD, (ii) the Flavian period until the earthquake in the middle of the 4th century AD, (iii) the proto-Byzantine period, and (iv) a the last phase after a destructive earthquake in the middle of the 7th century AD, when Hierapolis went into decline.

Beginning from 1957 the Italian Archaeological Mission in Hierapolis has been carrying out excavations and restorations in the city and in the surrounding large necropolises (D'Andria & Caggia, 2007).

Since 2003 archaeological surveys, based on the use of QB panchromatic imagery, have been in progress in the urban area (see figure 1b, Scardozzi, 2007a) and subsequently (2005) extended to cover a larger area neighboring the ancient city (Scardozzi, 2007b).

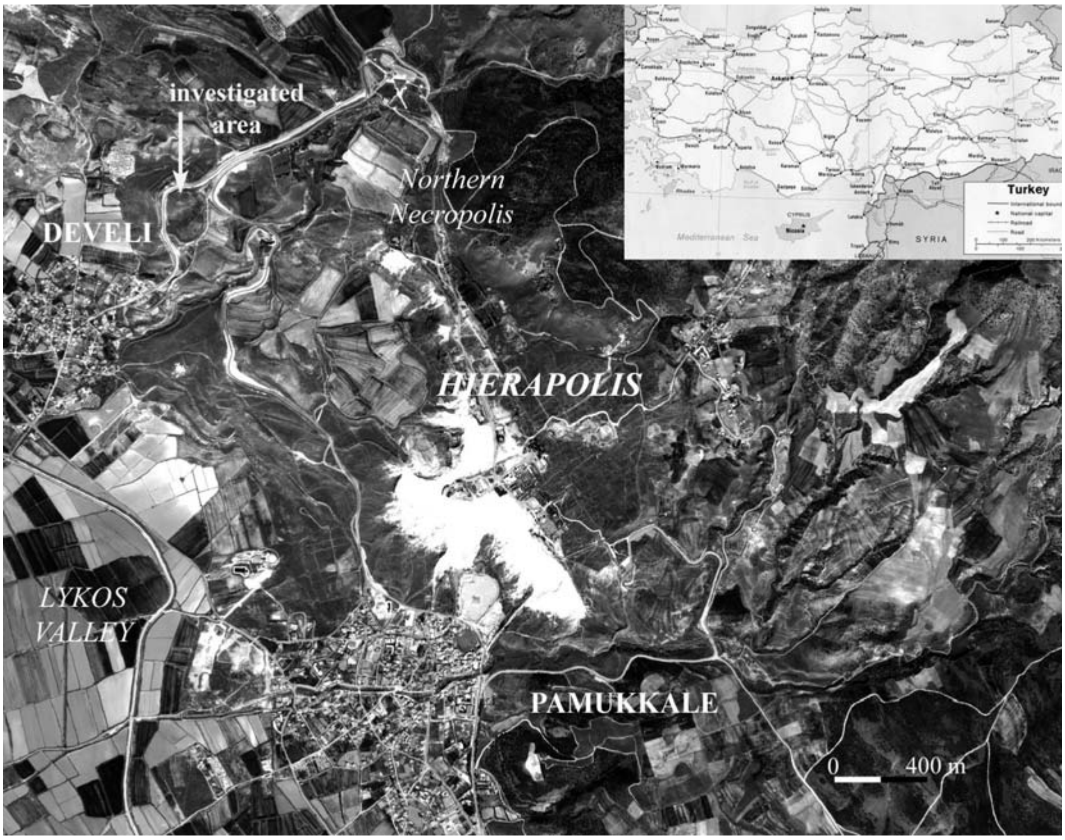


Figure 1. Study area.

3 DATA SET AND ANALYSIS

3.1 Data set

The QB data used for this study (Catalog ID 10100100041F7700) were acquired on the 25th March 2005 at 9.00 a.m. The QB dataset, made of one panchromatic at 0.6-m resolution and four multispectral images (from blue to near infrared bands) at 2.4-m resolution, were taken with an off nadir View Angle of 4.9 degrees, thus assuring a limited geometric distortion.

The presence of archaeological features can be revealed by using satellite imaging because the spectrum of sunlight reflected by the earths surface material contains information about the composition of the surface, and it may reveal spatial/spectral anomalies linked to traces of past human activities such as agriculture, walls, buildings, ancient roads etc The presence of buried and/or exposed remains was detected by using: (i) single spectral channels, (ii) spectral indices and Principal Component Analysis (PCA), (iii) data fusion. The QB -based analysis adopted for the identification of superficial anomalies is shown in figure 2.

(i) single spectral channels

From a multispectral remote sensing perspective, the different marks linked to the presence of buried or exposed archaeological remains should be detected using specific spectral channels In particular, the QB panchromatic scenes acquired during early morning or late afternoon have been found to be capable to enhance shadow marks linked to micro-topographic relief of surfacing remains.

The red spectral band was able to reveal soil marks accordingly to soil spectral signatures (Lasaponara & Masini, 2005) being that the presence of archaeological deposits under bare surface strongly influence the soil constituents and color, grain size and moisture content.

The near-infrared (NIR) band allowed us to better enhance crop-marks (Lasaponara & Masini, 2007), according to the typical vegetation spectral signature/characteristics. Archaeological remains such as ditches and walls, buried under vegetated surface strongly influences the state of plants, enhancing or reducing vegetation growth, colour and phenological state.

(ii) spectral indices and Principal Component Analysis (PCA)

The spectral indices, obtained by combining different spectral bands, are quantitative measures of surface properties. Spectral indices, attempt to quantify surface properties such as brightness, moisture, biomass cover, or vegetative vigour. Usually, the numerator band is chosen in which the material is highly reflective, whereas the denominator is a band covering an absorption feature for that material. In particular, vegetation indices are mainly derived as a ratio between near-infrared and red reflectance.

The Principal Component Analysis (PCA) is a linear transformation which decorrelates multivariate data by translating and/ or rotating the axes of the original feature space, so that the data can be represented without correlation in a new component space.

The PCA transforms the input multispectral bands in new components whose number is equal (or less) to the input channels. The first component contains the major portion of the variance, each successive component contains less of the total dataset variance. The first component provides a sort of average of all the input channels, whereas the later components may represent information variance for a small area or essentially noise. In the latter case it must be disregarded. Some problems can arise from the fact that eigenvectors can not have a general and universal meaning since they are extracted from the data set itself. Therefore, a part for the first PCA component, it is not possible to give a general indication on the meaning of the later PCA components.

(ii) data fusion

Image fusion refers the process of combining multiple images of a scene to obtain a single composite image. The different images to be fused can come from different sensors of the same basic type or they may come from different types of sensors. The composite image should contain a more useful description of the scene than provided by any of the individual source images. In the current cases under investigations the QB panchromatic and multispectral images were fused by using a data fusion algorithm based on least squares for founding the best approximation between the fused image bands and the original data to obtain the maximum increasing of details coupled with a minimum distortion. This algorithm has been adopted by Digital Globe [http://www.pcigeomatics.com/support_center/tech_ papers/techpapers_main.php] and it is also available in a PCI-Geomatica routine.

3.2 Data analysis

QB images were used in all phases of the research. First of all, they provided useful information for the field surveys compensating for the lack of up to date maps. The best topographical maps available for the study area were on a scale of 1:25,000, and were drawn in the 1990s. These maps were suitable for an overview of the territory, but of little help in the field work. In this case, satellite images constituted a basic tool for the direct exploration of the territory and for the recording and exact positioning of archaeological evidence.

The analysis of satellite QB data allowed us to detect signs of intensive occupation of the territory. A number of potential archaeological evidence (see figure 2) was identified, analyzed and verified by the field survey, thus contributing to a detailed reconstruction of the historical development of the territory from prehistoric times to the modern period. In this paper, we focused from the Hellenistic to the Byzantine age. Relating to this period, several rural settlements were found in the area surrounding Hierapolis, some of them are circled in figure 2. During the Roman and Byzantine periods the whole area and its settlements were under the administration of the city. Some of these farms were constructed with small blocks extracted from nearby travertine quarries. In fact, the discovered structures often present remains of exposed walls in travertine blocks. On the ground the visible remains of these ancient farms were sometimes negligible, but the processing of the satellite images highlighted the traces of buried walls. External perimeter and internal structures of the ancient buried edifices were successfully identified and spatially characterized by QB images.

As an example, in this paper we focused on a significant rural settlement located on the top of a small hill at around 1.3 km North-West of Hierapolis. The archaeological remains were situated in a bare area sparsely covered by spontaneous plants.Satellite panchromatic image was used in discriminating potential archaeological features (figure 3a). Such features were found to be related to the external perimeter of the buried building (that is indicated as A in figure 3d), having a rectangular shape. Enhancement techniques, such as spectral indices and PCA, were also employed in order to improve the contrast of the above said features. The significant presence of fragments of travertine blocks, tiles, coarse ware (see figure 4) made difficult the identification of internal walls. Significant results were only obtained from the first component of the PCA (figure 3b). This is in perfect accordance to the fact that the first PCA substantially provide a map very close to the brightness and similar to the panchromatic image. Figure 3c shows the RGB composition (R=red, G=NIR, B= pan). Overall, the performed analysis enabled us discriminate the main building, indicated as A in figure 3d and traces of external walls indicated as B in figure 3d. The ground truth confirmed the archaeological interest of the identified features (figure 4). In particular, the features which compose the perimeter of the building were on the top of the hill and mainly identified as the typical micro-relief anomalies (shadow marks). Whereas, the external walls were given by remains of a prominent terracing wall which cut into the slope immediately in the South-Ovest side of the building .

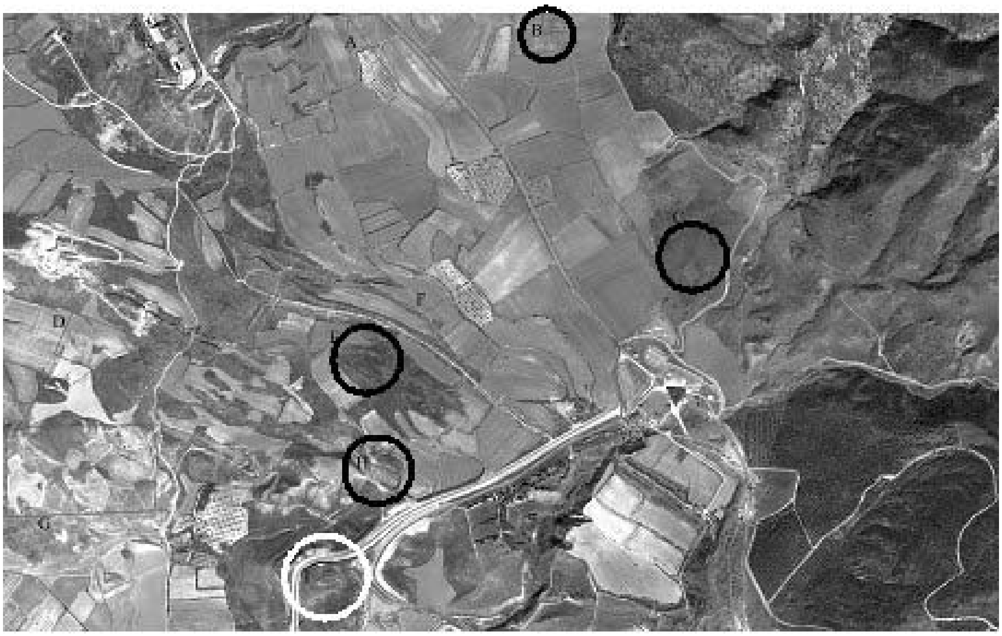


Figure 2. The circles indicate all the rural settlements discovered by means the integration of satellite based processing and field survey. The farm investigated in this paper is white circled.

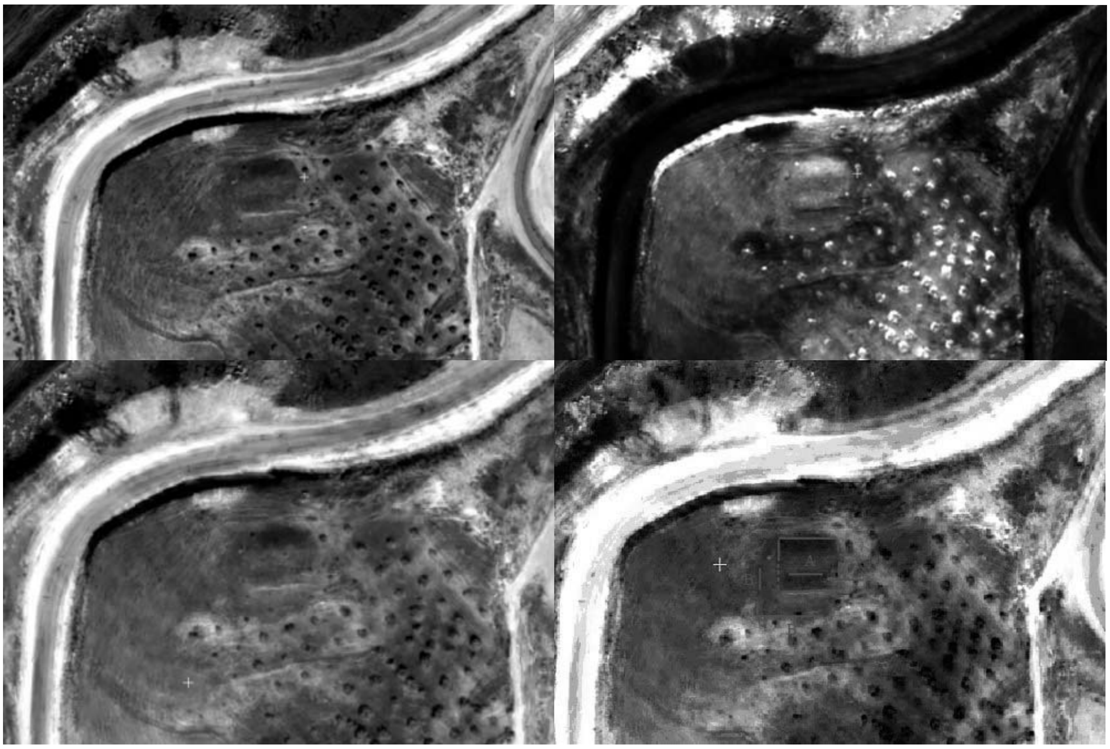


Figure 3. (a) QB panchromatic image; (b) PC1 component; (c) RGB composition (R=red; G=NIR, B=pan); (d) spatial characterization. A indicated the external walls of the farm and B denotes remains of prominent terracing structures.

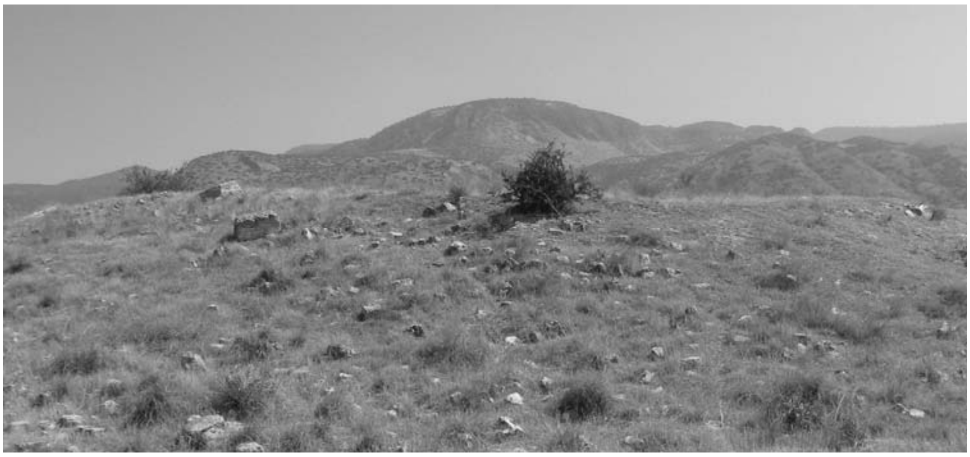


Figure 4. Detail of the site. In evince fragments of travertine blocks, tiles, coarse ware and dolia which permitted to attribute the building to a farm and to date it to a period between the early Imperial Roman and the proto-Byzantine age

Finally, the finding of fragments of travertine blocks, tiles, coarse ware and *dolia* permitted to attribute the building to a farm and to date it to a period between the early Imperial Roman and the proto-Byzantine age.

4 FINAL REMARKS

In this paper the QB satellite images were used for supporting archaeological investigations performed in the neighboring of the ancient urban area of Hierapolis of Phrygia (South East of Turkey). Results obtained from QB data analysis allowed us to detect a number of potential archaeological features, among them we focused on ancient remains from the Hellenistic to the Byzantine age when the whole area was under the administration of the city. Relating to this period, a relevant system of rural settlements was found in the area surrounding Hierapolis. In this paper, a significant test site has been detailed. Analysis performed from satellite images and field survey allowed us to identify the ancient building. On the ground the visible remains of this ancient farm was quite negligible, but the processing of the satellite images highlighted the traces of buried walls. External perimeter and structures of the ancient buried edifice were successfully identified and spatially characterized by QB images.

REFERENCE

Lasaponara, R., Masini, N. 2005. QuickBird-based analysis for the spatial characterization of archaeological sites: case study of the Monte Serico Medioeval village, *Geophysical Research Letter*, 32, 12, L12313, 2005.

Lasaponara, R., Masini, N. 2007. Detection of archaeological crop marks by using satellite QuickBird, *Journal of Archaeological Science*, 34: 214-221, 2007.

D'Andria, F., Caggia, M. P. (Eds), 2007. *Hierapolis di Frigia, I, Le attività delle campagne di scavo e restauro 2000-2003*, Ege Yayınları, Istanbul.

Scardozzi, G. 2007a: L'urbanistica di Hierapolis di Frigia: ricerche topografiche, immagini satellitari e fotografie aeree, in *Archeologia Aerea. Studi di Aerotopografia Archeologica*, II : 83-124.

Scardozzi, G. 2007b. Remote sensing and archaeological survey in the Hierapolis of Phrygia territory, Turkey, in Remote Sensing for Environmental Monitoring, GIS Applications and Geology, Conference 6749 "Remote Sensing and Archaeology". *Proceedings of SPIE Europe Remote Sensing* (Florence 17-20 September 2007),6749, 674904/1-12, 2007.

Detection of burial mounds in high-resolution satellite images of agricultural land

Ø. Due Trier[1], A. Loska[2], S. Øyen Larsen[1], R. Solberg[1]

1 *Section for Earth Observation, Norwegian Computing Center, Gaustadalléen 23, P.O. box 114 Blindern, NO-0314 Oslo, Norway, oivind.due.trier@nr.no; siri.oyen.larsen@nr.no; rune.solberg@nr.no*

2 *Norwegian Directorate for Cultural Heritage, P.O. Box 8196, N-0034 OSLO, Norway, anke.loska@ra.no*

Keywords: QuickBird satellite images, template matching, contrast enhancement, crop marks, soil marks

ABSTRACT

Many archaeological sites are discovered during building and road construction work, prompting full excavations and delay in construction. In order to detect more cultural heritage sites in advance of construction work, the Norwegian Directorate for Cultural Heritage has taken an initiative to develop tools for early detection of potential cultural heritage sites in satellite images. The present work focuses on detecting the remains of burial mounds in agricultural fields.

The remains of destroyed burial mounds are sometimes visible in satellite images as circular soil marks or crop marks. At best, the marks are distinct, but tend to have less contrast to the background than many other patterns in the images. Consequently, reliable automated detection based on pattern recognition is challenging.

We have developed an approach with the following steps. First, the image is contrast enhanced, in order to make weak marks more distinct. The image is then convolved with ring templates of varying sizes, giving high absolute values at candidate ring locations. Finally, the ring candidates are presented to an operator, who may reject some of them.

We tested our method on Quickbird images from south-east Norway. Of the circular marks that were clearly visible in the images, 73% was detected, and of the ones that were fairly visible, 50% was detected. In addition, seven times as many false positives as true positives were detected. The number of false positives can be reduced, at the cost of reducing the number of true positives as well. For example, by reducing the number of false positives from 7 times to 0.5 times the number of true positives, the number of detected rings decreased from 64% to 32%.

Archaeologists state that the software tool will be helpful for locating potential cultural heritage sites. Although it makes many false detections, the interactive method to delete false detections is so efficient that, say, ten times as many false detections as true detections is not considered a problem by archaeologists.

1 INTRODUCTION

The increasingly intensive use and modification of the landscape resulting from modern demands for efficient infrastructure and land use (agricultural production, mining, energy sources, leisure/tourism facilities, etc.) exerts growing pressure on cultural heritage in the landscape. In order to match the political intentions of updated and sustainable cultural heritage management, it is necessary to develop a cost-effective method for locating and monitoring cultural heritage sites. Given the enormous costs of surveying the areas in question by traditional fieldwork, alternatives must be sought. The use of modern support technologies is imperative, if such rapid changes are to be balanced against the sustainable management of this resource. One possible approach is through the use of satellite images.

In recognition of this, the Norwegian Directorate for Cultural Heritage – in collaboration with the Norwegian Computing Center, the Norwegian Institute for Cultural Heritage Research, the Museum of Cultural History at the University of Oslo, and Vestfold County Administration – started in 2002 a project with the overall aim of developing a cost-effective method for surveying and monitoring cultural heritage sites on a regional and national scale. Important funding was provided by the Norwegian Space Centre.

Results obtained in a pilot project (Grøn, 2004) indicated the existence of a correlation between cultural heritage sites and variation in the chemical elements in the soil. A central focus in the early project years was the manual analysis of satellite images followed by chemical profiling of sites observed in these images in order to gain experience as to how cultural heritage sites really manifest themselves in satellite images. The results demonstrated that high-resolution geo-chemical sampling appears to be a promising field for the development of cultural heritage indicators. However, the costs involved demanded a need for funding which was difficult to obtain.

It was then suggested to focus on the development of automated methods, such as pattern recognition, for detecting and locating cultural heritage sites. The working assumption is that cultural heritage sites with no visual apparent manifestations above ground may be detectable in remote sensing images due to alterations in the spectral signature of the bare soil or of uniform vegetation growing there (crops).

The use of aerial imagery for this purpose is quite widespread (e.g., Campana, 2006a; Musson, 2006). In addition to airborne multispectral imaging, recent advances in airborne LIDAR also show great promise (e.g., Risbøl, 2006; Sittler, 2006). The collection of airborne imagery and LIDAR is nevertheless both time consuming and costly and this imposes severe limitations on the size of the areas that can be investigated. In this respect satellite imagery holds great promise. Satellite image based location, surveillance and monitoring of cultural heritage sites has been the subject of some recent research (e.g., Aurdal, 2006; Lasaponara & Masini, 2006; Campana, 2006b), but generally this field is not well explored.

Although the costs connected with acquiring and analyzing the satellite data will not be insignificant, and fieldwork will never be replaced entirely by high-technological methods, it seems plausible that an essentially cheaper and possibly even qualitatively better method for the surveying and monitoring of cultural heritage sites can be developed to target fieldwork to a degree not possible today.

2 THE CULTSEARCHER PROTOTYPE SYSTEM

The CultSearcher prototype system is currently analyzing soil-marked and crop-marked patterns. Soil-marked sites are typically the remains of a ditch or pit, buried walls, etc. A ditch or a pit would disturb the local soil profile, and refilled material usually has different characteristics, like density and composition. The refilled material is in most cases not so compact, and it might contain more humus components, making it look darker. The refilled material may also affect the soil texture with a grain-size distribution that differs from the undisturbed soil (usually larger number of smaller grain sizes). This results in improved water-storage capacity, so the soil would look darker under certain conditions.

Crop marks are an indirect effect of buried archaeological features. Their visibility depends on the soil, climate and vegetation. So-called positive marks are due to more available water, which makes plants grow higher and ripen later than the plants around. A colour-tonal contrast may be created because the vegetation stays green for a longer period and/or that the vegetation is darker green. Crop marks may also be due to a vegetation relief. Plants grow higher, enough to throw a shadow in slanting sunlight. So-called negative marks appear when plants grow over buried stones (e.g. walls) and run out of water sooner, ripen earlier and stay shorter. Almost any crop can develop marks, if conditions are well. Cereals react fast on a Soil Moisture Deficit (SMD) and are growing very close, making contrasts clearer.

Various types of remote sensing sensors, airborne and spaceborne, are useful for detecting remains or patterns due to cultural heritage sites. Soil- and crop-marked sites can be measured with high-resolution optical (visible and infrared) sensors. With the optimal selection of observation wavelengths, high contrast can be obtained (in particular appearing from reflectance contrasts due to soil moisture or vegetation density). The spatial resolution of these sensors should be of 1 m or better to be really useful. Therefore, the project has so far focused on images from Ikonos and Quickbird.

The aim of the software prototype described in this report is to provide computerized assistance to the operator in the analysis of satellite images. In particular, the software identifies circular structures, i.e., potential sites for the remains of bronze age burial mounds, for further inspection by an archaeologist. This means that the archaeologist may concentrate on analyzing the identified sites rather than the entire image. It is important to bear in mind that the system is designed to detect candidate sites and that no claim is made that these candidates are true cultural heritage sites. Even human specialists cannot make such an assertion based on satellite imagery alone. The verification of a potential site always depends on some kind of field inspection.

In order to detect as many circular marks as possible, while at the same time keeping the number of false positives at a minimum, variations of the following sequence of methods have been tried out: (1) band pass filtering in the frequency domain, (2) local contrast enhancement, (3) template matching, (4) feature extraction, and (5) decision tree-based classification

The details are given in (Trier, 2008). Experiments in that study concluded that methods 2 and 3 were vital, whereas the three other methods gave no improvement in the recognition results. The resulting algorithm for ring structure detection can be summarized as follows.

1. Define masks of agricultural fields, either done interactively or by importing a GIS file.
2. Apply local contrast enhancement.

3. Search for rings: (a) construct ring templates of increasing sizes, (b) convolve image with a ring template, (c) threshold result of step b to find bright rings, (d) threshold result of step b to find dark rings, and (e) repeat steps b-d for all ring template sizes.

3 EXPERIMENTAL DATA

The data set consists of two Quickbird images from south-east Norway. One was taken on April 27, 2005 at 10:45AM, from the valley Lågendalen between Kongsberg and Larvik. The other was taken on July 29, 2003 at 10:23 AM, from an area surrounding, but not including, the Oslo Gardermoen airport. Both images consist of a four-band multi-spectral image and a panchromatic (grey scale) image. The panchromatic image has 0.6 m wide pixels, and the single band covers the 450-900 nm wavelengths. The multi-spectral image has 2.4 m wide pixels, and the bands are: blue (450-520 nm), green (520-600 nm), red (630-690 nm) and near-infrared (760-900 nm).

Many circular patterns are clearly visible in the panchromatic images, but can hardly be seen in the multi-spectral images. Recently, other research groups have used multi-spectral Quickbird (Lasaponara & Masini, 2007) or Ikonos (De Laet, 2007) images, but the objects they were looking for were much larger than the circular patterns in the present work. Since the circular patterns are difficult to spot visually in the multi-spectral images, we chose to use only the panchromatic images.

In the two images, archaeologists have identified 35 rings that they would like the system to recognize. We have visually classified 15 of these as “strong”, 10 as “fair” and 10 as “weak” 11 subimages of 4096×4096 pixels were extracted for the experiments. These subimages included all 35 rings.

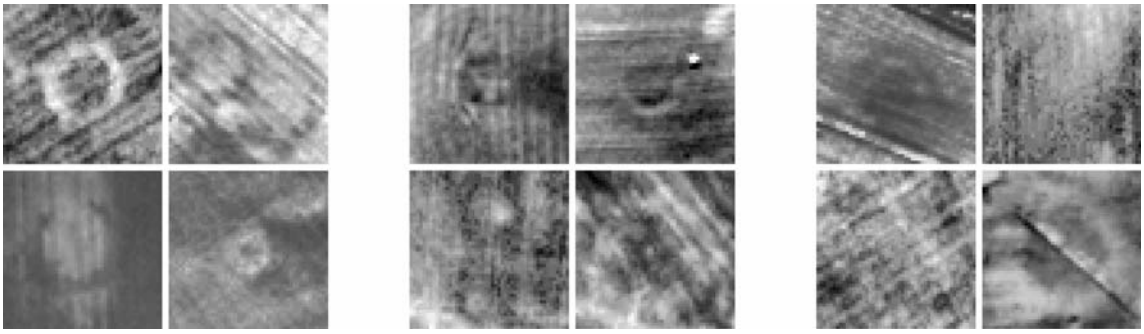


Figure 1 Example rings. Left: strong, center: fair, and right: weak.

4 EXPERIMENTAL RESULTS

The above algorithm was applied to the entire data set, that is, a collection of 11 sub-images of sizes 4096×4096 pixels, which together covered all the identified true rings.

The number of detected false rings varies dramatically with the correlation threshold (). A reasonable compromise between not detecting too many false rings and at the same time detect as many true rings as possible, might be when the number of false detections is approximately seven times the number of true detections (yellow line in). In this case, 11 out of 15, or 73%, of the strong rings were detected, and 5 out of 10, or 50%, of the fairly strong rings were detected. This is 16 out of 25 of the strong and fairly strong rings, or 64%.

The number of false positives can be reduced, at the cost of reducing the number of true positives as well. For example, by reducing the number of false positives from 7 times to less than half the number of true positives, the number of detected rings decreased from 64% to 32%. On the other hand, even if the correlation threshold is set so low that almost 30 times as many false rings as true rings are detected, many of the strong and fairly strong rings are not detected. Further, none of the weak rings are detected.

correlation threshold	strong rings	fair rings	weak rings	total true rings	false rings
0.3	11	5	0	16	450
0.33	11	5	0	16	109
0.35	10	2	0	12	39
0.4	8	0	0	8	3
Identified true rings	15	10	10	35	

Table 1. Detection results

5 DISCUSSION AND CONCLUSION

The experiments demonstrate that the proposed algorithm is able to detect many circular patterns. Still, many are also missed by the algorithm. If the goal is to detect each and every circular pattern, then the algorithm needs to be improved to be really useful. For a thorough search in a limited area, a high number of false positives might be acceptable. On the other hand, for massive search through a large number of images, the number of false positives might be kept at a minimum, as long as *some* sites are detected. Some circular patterns may only be visible from time to time. In order to find these, one may have to process images from, say, a ten year period, and, say, 5-10 images per year. In this perspective, our approach can be used to process large volumes of satellite images that would otherwise not be inspected, thus detecting many new sites.

At present, only one parameter is varied for the different ring templates, namely the radius. One could also vary the thickness of the ring, and see if that enables us to use a high correlation threshold, possibly eliminating many of the false detections while at the same time detecting more true rings.

In this work, we have only used two satellite images, containing in total 35 identified rings. Many more satellite images and identified rings are needed to evaluate the current version of the system, spot weaknesses and experiment with possible enhancements.

Archaeologists state that the software tool will be helpful for locating potential cultural heritage sites. Although it makes many false detections, the interactive method to delete false detections is so efficient that, say, ten times as many false detections as true detections is not considered a problem by archaeologists.

6 REFERENCES

Aurdal, L., Eikvil, L., Koren, H., Loska, A. 2006. Semi-automatic search for cultural heritage sites in satellite images. *Proceedings of "From Space to Place", 2^{nd} International Conference on Remote Sensing in Archaeology*, Dec. 4-7 2006, Rome, Italy, BAR International Series 1568, pp 1-6.

Campana, S., Frankovich, R., Pericci, F., Corsi, M. 2006a. Aerial survey project in Tuscany: years 2000-2005. *Proc. "From Space to Place"*, Dec. 4-7 2006, Rome, Italy, pp 497-503.

Campana, S., Piro, S., Felici, C., Ghisleni, M. 2006b. From space to place: the Aiali project (Tuscany-Italy). *Proc."From Space to Place"*, Dec. 4-7 2006, Rome, Italy, pp 131-136.

De Laet, V., Paulissen, E., Waelkens, M. 2007. Methods for the extraction of archaeological features from very high-resolution Ikonos-2 remote sensing imagery, Hisar (southwest Turkey). *Journal of Archaeological Science*, vol. 34(5), pp. 830-841.

Grøn, O., Aurdal, L., Christensen, H., Tømmervik, H., Loska, A. 2004. *Locating invisible cultural heritage sites in agricultural fields: Evaluation of Methods for Satellite Monitoring of Cultural Heritage Sites – Results 2003.* The Norwegian Institute for Cultural Heritage Research, Tech. Rep., ISBN: 82-7574-033-9, March 2004.

Lasaponara, R., Masini, N. 2006. Performance evaluation of data fusion algorithms for the detection of archaeological features by using satellite Quickbird data. *Proc. "From Space to Place", 2^{nd} International Conference on Remote Sensing in Archaeology*, Dec. 4-7 2006, Rome, Italy, BAR International Series 1568, pp 13-21.

Lasaponara, R., Masini, N. 2007. Detection of archaeological crop marks by using satellite QuickBird multispectral imagery. *Journal of Archaeological Science*, 34(2), pp. 214-221.

Musson, C., Driver, T., Pert, T. 2006. Air photo applications in Wales, UK. exploration, landscape analysis, conservation and public presentation. *Proc. "From Space to Place"*, Dec. 4-7 2006, Rome, Italy, pp. 55-60.

Risbøl, O., Gjertsen, A. K., Skare, K., 2006. Airborne laser scanning of cultural remains in forests: some preliminary results from a Norwegian project. *Proc. "From Space to Place"*, Dec. 4-7 2006, Rome, Italy, pp 107-112.

Sittler, B., Schellberg, S. 2006. The Potential of LIDAR in Assessing Elements of Cultural Heritage Hidden Under Woodland Canopies. Possibilities and Limits in Detecting Microrelief Structures for Archaeological Surveys. *Proc. "From Space to Place"*, Dec. 4-7 2006, Rome, Italy, pp 117-122.

Trier, Ø. D., Larsen, S. Ø., Solberg, R. 2008. *Detection of circular patterns in high-resolution satellite images of agricultural land with CultSearcher.* Note no SAMBA/16/08, Norwegian Computing Center, http://publ.nr.no/

A view on Greater Angkor: a multi-scalar approach for investigating the Khmer forests

A. Traviglia

Department of Archaeology – ACL, University of Sydney, 2006, NSW, Australia, atraviglia@usyd.edu.au

Keywords: Angkor (Cambodia), multispectral analysis, Vegetation Indices, PCA, ASTER, Quickbird, Ikonos

ABSTRACT

This paper will focus on the results of a joint international project (a partnership between the University of Sydney and the University of Venice) that develops and applies satellite remote sensing methodologies for finding and mapping unknown archaeological sites in the surroundings of Angkor, in Cambodia. Long famous for its temples, this World Heritage site is now increasingly recognized as a vast, low-density urban landscape.

The project consists of using the spectral content of remotely sensed images to reveal the presence of buried sites and structures of the ancient Khmer landscape on the basis of the different spectral characteristics of the terrain and vegetation. By applying spectral analysis, the current research aims to scan vegetated and bare soil areas in order to clarify features that are ambiguous in existing maps and reveal features which would otherwise remain undetected

1. INTRODUCTION

With the aim of supporting sustainable development of the Cambodian regional ecosystem and the management of Angkor as a national and an international cultural resource, the University of Sydney has been collaborating for an extended period with the Cambodian authorities in a number of innovative, multidisciplinary projects in the social sciences related to the ancient town of Angkor and its countryside, namely Living with Heritage (LWH) and Greater Angkor (GAP) projects, both receiving major funding from the Australian Research Council through 2009 and operating in partnership with international institutions and authorities.

The research presented[1] here forms a part of the GAP project and aims to contribute to the work already done by exploiting acquired and newly acquired remotely sensed data. Based on the diverse experience of the participants, the project intends to develop and apply mature strategies of satellite RS for detection of archaeological unknown or not otherwise detectable features and monuments, integrating past and future research and international heritage best-practises.

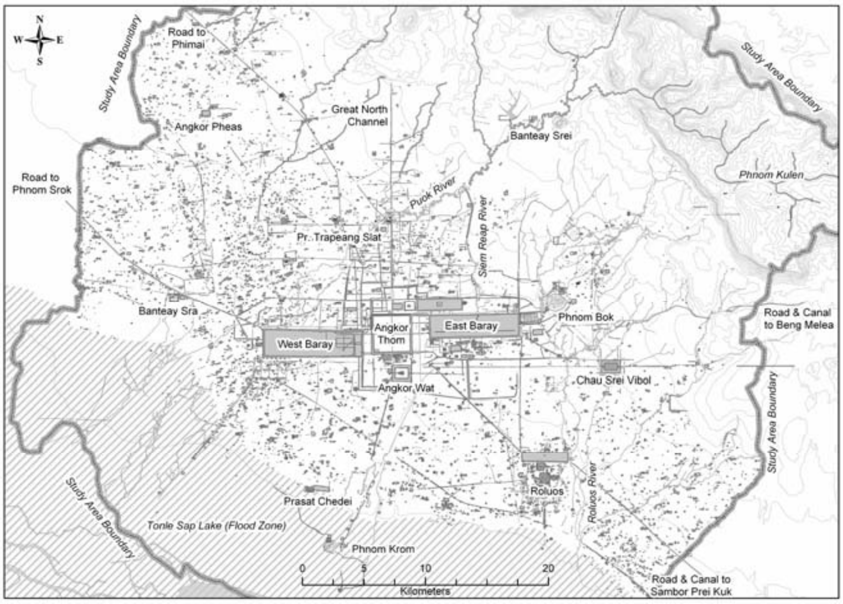


Figure 1. The Greater Angkor, after Evans-Pottier 2007 (image courtesy of PNAS)

---

[1] "*Mapping the past using advanced technologies: Satellite applications for uncovering archaeological remains at Angkor*", *ARC International Linkage* funded project.

1.1 The Greater Angkor Project (GAP): 10 years of USYD research on Angkor.

The GAP is a collaborative project between the University of Sydney (Dir. R. Fletcher), the Ecole française d'Extrême-Orient (EFEO) and Authority for the Protection and Management of Angkor (APSARA). Since 1999, GAP worked for mapping and analyzing the urban layout of Angkor with an aim to understanding the role of the water management system in Angkor's demise.

The project focuses on northern reaches of the ancient town, where radar images taken from a NASA Space Shuttle in 1994 indicated that a vast and complex extension to Angkor's water management system might be found. New radar data JPL AirSAR data (2000) and other remote sensing data provided the foundation for a seven-year study by Dr. D. Evans (University of Sydney) on mapping the further reaches of Angkor's urban complex (Evans et *al.,* 2007). In August 2007 the publication of the results of this long project revealed the entirety of Angkor's extremely complex water management system. Although the precise boundaries of Angkor's urban sprawl are still difficult to define, the new map discloses Angkor as probably the largest integrated network of known urban space (fig. 1).

2. MULTISPECTRAL REMOTE SENSING ON THE ANGKORIAN LANDSCAPES

Starting from the results so far achieved from the GAP this project seeks to exploit the spectral characteristics of the relevant amount of RS data collected over Angkor landscape in the past years. The spectral content of remotely sensed images is being used to reveal the presence of buried sites and structures of the ancient Khmer landscape on the basis of the different spectral characteristics of the terrain and vegetation.

As previously stated, multispectral and radar data have already been adopted in the GAP team to detect and draw maps of archaeological monuments or possible archaeological features like village ponds, canals, roadways and temples (Fletcher *et al.,* 2002). Landsat TM data were used in an attempt to locate a possible boundary for the distribution of surface artifacts which define the Angkorian settlement landscape in 2002. An Ikonos scene acquired over Angkor was also available for the analysis; however, its spatial coverage was relatively limited. A complete coverage of ASTER scenes was available during the analysis due to an archaeological research being carried out by Dr. M. Hendrickson (2006). AirSAR airborne radar system has been used from 2002 as a method of archaeological data collection (Fletcher *et al*., 2004).

The outcomes of the use of remotely sensed data so far have been satisfactory, leading to detection and mapping of a large number of features with different levels of certainty about their origins, but the process is still partially incomplete as regards specific areas. Deficiencies within the existing maps are ascribed to particular environmental conditions: for example, a large part of the investigated area is strongly forested. Previous shortcomings with the multispectral data are due to the fact that the analysis was mainly performed through a simple on-screen visual investigation of the raw data. Significant results can now be achieved exploiting the spectral characteristics of the satellite images through image processing. Consequently various satellites images (ASTER, Landsat TM, Ikonos, Quickbird) have already been or will be soon submitted to image processing techniques, accordingly to the type of natural environment of the target area they represent. The ambiguity caused by vegetation cover, for example, can be at least partially overcome using spectral content of the images. For this reason particular emphasis is given in our research to Vegetation Indices (VI): the vegetation covering archaeological features and hiding them to a pedestrian, aerial or radar survey have in fact specific spectral signatures that can be detected through image processing, possibly leading to the identification of subsurface archaeological structures.

Here only the first results of spectral analysis achieved so far using ASTER data will be presented, since the Quickbird and Ikonos data are still under process and results consequently under evaluation.

2.1 ASTER data: previous and current use

Forty ASTER tiles (ASTER L1A reconstructed unprocessed instrument data v003) have been acquired for GAP in the past years; the data were collected in different periods of the year between 2002 and 2003. On screen visual analysis have been performed in the past on all of them (Dr. M. Hendrickson – University of Sydney), leading to the identification of the location, the mapping and the analysis of the extant remains of the angkorian road network across northern Cambodia and southern Laos.

In the current project, investigation exploiting the spectral content of ASTER data are being performed and tested. While evaluation of the outcomes and new processing are still in progress, what will be discussed next are the first results of the application of Vegetation Indices and Principal Component Analysis (PCA).

2.2 Mapping vegetation: quality assessment Indices (VI)

The primary limitation of the mapping work previously carried out by using radar and satellite data was the forest cover, which tended to obscure the settlement artifacts in large tracts of the study area. Additionally, a portion of the study area was covered by light vegetation, including scrubland and sparse forest presenting some problems for detection of archaeological objects. In this type of environment features can be identified by slight differences in the biomass of the vegetation cover detectable in the spectral imagery. Consequently wide application is being given in this research to Vegetation Indices, since studies about the quality of the vegetation, monitoring variations in its vigor, can enable the detection of subterranean archaeological deposits that allow or limit the growth of the vegetation. Heterogeneity of the texture of the subsoil has in fact a strong impact on the growth of the vegetation, creating the manifestation of "marks" over the vegetation canopy. Calculation of different types of VIs can achieve different results for archaeological purposes, depending on the vegetation coverage type and the density of the canopy, both being primary factors to keep in consideration when selecting the appropriate process to evaluate the biomass of a certain area, since they can strongly affect the results of the process itself. The most suitable procedure to follow is to perform and test different vegetation indices after a careful consideration of the environmental and morphological study case area characteristics (Traviglia, 2006). The results gained are first being compared among themselves to determine the best method for evaluating vegetation health in the target spot and secondarily with the original images in order to verify the improvement of the visibility of traces they offer. So far 2 VIs have been calculated and tested, whose the formulas are well known:

DVI (Difference Vegetation Index): $DVI=NIR/$ (1)

NDVI (Normalized Difference Vegetation Index): $NDVI=(NIR-R)/(NIR+R)$ (2)

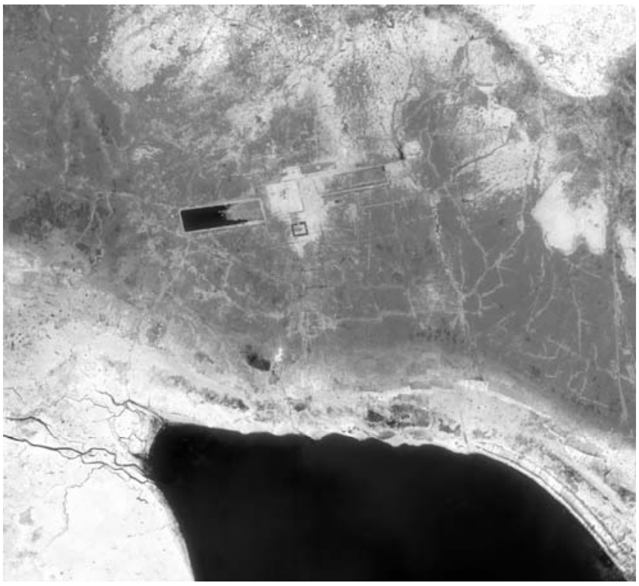


Figure 2. NDVI of ASTER data.

As preliminary results we have noticed that the NDVI (fig. 2) has proved to have better sensitivity than DVI to changes in vegetation cover and compensating for changing illumination conditions and other extraneous factors like areas where there is a shadow effect. This is particularly true in determined environmental circumstances, like in case of high vegetation cover, while the index showed its sensitivity to canopy background variations when applied in areas of low or sparse vegetation. Based on previous experience with these vegetation indexes, the aim in the prosecution of the research is to test a larger number of indices to identify those that can better fit specific situations not investigated before, like, for example, partially submerged vegetation.

2.3 Highlighting surface changes: the Principal Component Analysis (PCA)

Supplementary information compared to the original bands and a better discrimination of different surfaces rendered more distinguishable for visual analysis have been obtained through the application of the Principal Component Analysis (PCA), a process aiming to reduce the redundancy in data by transforming a set of correlated variables into a new set of uncorrelated ones. Through this process the information previously contained in the original n- band data set is reduced into a smaller number of new bands that can be used in place of the original ones. This is particularly useful when dealing with images like ASTER composed by an elevated number of bands.

Several surface features in areas of bare soil or low and sparse vegetation have been highlighted when applying this process to the Khmer landscape. Other tests will be soon executed and ground truthing conducted in order to define the level of improvement in quality of the image trace visibility.

A particular type of PCA, a Selective Principal Component Analysis (SPCA) has been tested in order to magnify the results already obtained with PCA. The SPCA is a Principal Component Analysis computed for spectral subsets, that is to say groups of bands, e.g. belonging the same spectral region. As an output, better results in terms of recognizable features compared to normal PCA can be obtained (fig. 3).

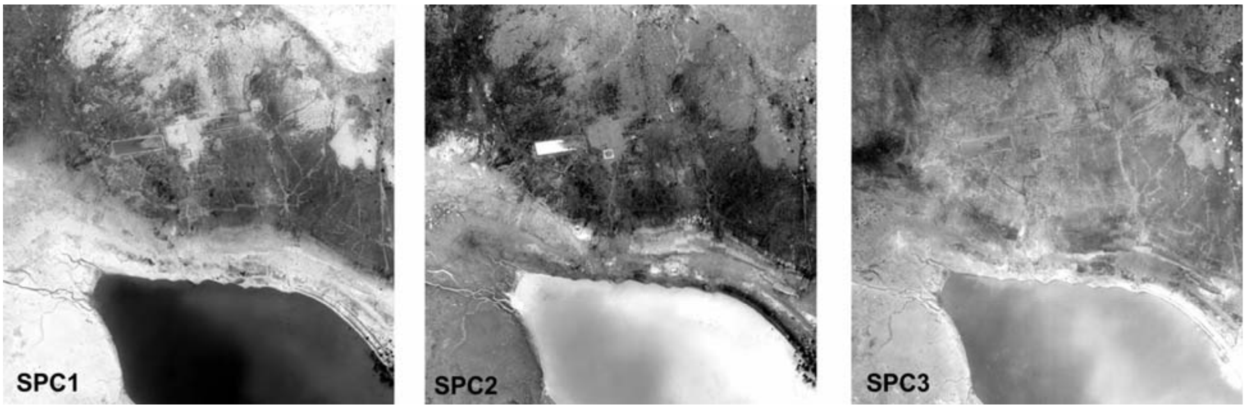


Figure 3. First 3 Components of a SPCA performed on VNIR bands.

3. ACHIEVEMENTS AND FURTHER DEVELOPMENTS

The availability of many remotely sensed data for the needs of the project allows a multi-scalar and multi-temporal approach for the detection of archaeological features and will permit the identification of a larger set of typologies of features. While, for example, ASTER data proved to be useful in the detection of large hydrological systems of which the landscape is rich, higher resolution data like Quickbird currently under examination promise to permit the detection of small features and recognize a pattern in their location; currently the Quickbird data led to the detection of a temple area and traces of a palaeo-riverbed. Thus far also Ikonos data are showing a great potential for the investigation of highly vegetated areas, where a red band intensively highlighted different typologies of vegetation. The results of the investigation of the treated images augment the current map of greater Angkor and are crucial for a correct understanding of the extension of the Khmer settlement and of the processes which led to its decline and abandonment.

4. REFERENCES

Evans, D., Pottier, C., Fletcher, R., Hensley, S., Tapley, I., Milne, A., Barbetti, M. 2007. A comprehensive archaeological map of the world's largest pre-industrial settlement complex at Angkor, Cambodia, *Proceedings of the National Academy of Sciences of the United States of America*, 104 (36): 4277-4282.

Fletcher, R., Barbetti, M., Evans, D., Than, H., Sokrithy, I., Chan, K., Penny, D., Pottier, C., Somaneath, T. 2003. Redefining Angkor: Structure and environment in the largest, low density urban complex of the pre-industrial world, *UDAYA Journal of Khmer Studies,* 4: 107-121.

Fletcher, R., Evans, D., Tapley I.J. 2002, AIRSAR's contribution to understanding the Angkor World Heritage Site, Cambodia - Objectives and preliminary findings from an examination of PACRIM2 datasets, in *Proceedings of the 2002 AIRSAR Earth Science and Application Workshop, NASA/JPL (National Aeronautics and Space Administration, Pasadena, CA)*, available at http://airsar.jpl.nasa.gov/documents/workshop2002/papers/P1.pdf

Fletcher, R., Evans, D., Tapley I.J., Milne A. K. 2004. Angkor: Extent, settlement pattern and ecology. Preliminary results of an AIRSAR survey in September 2000, *Bulletin of the Indo-Pacific Prehistory Association,* 24: 130-138.

Traviglia, A. 2006, Archaeological usability of Hyperspectral images: successes and failures of image processing techniques, in Campana S., Forte M., *From Space to Place. Proceedings of the 2nd International conference on Remote Sensing in Archaeology, Rome, December 4-7 2006*, Oxford, Archaeopress, 123-130.

Satellite remote sensing geoarchaeology of the ancient silver mine of Jabali, Yemen

J.-P. Deroin[1], F. Téreygeol[2], I. N.Al-Ganad[3],P. Benoit[4], J. Heckes[4]

1 Université de Reims, GEGENAA EA 3795, 51100 Reims, France, jean-paul.deroin@orange.fr
2 UMR 5060, Institut de Recherche sur les Archéomatériaux and CEA, Saclay, France, florian.tereygeol@cea.fr
3 Yemen Geological Survey and Mineral Board, Sana'a, Yemen
4 Université Paris 1 Panthéon-Sorbonne, Paris, France, Deutsches Bergbau-Museum, Bochum, Germany

Keywords: Mining Geology, Metalworking, Multispectral, DEM, Palaeoclimate

ABSTRACT: Jabali in the Republic of Yemen was mined for silver during the pre-Islamic period and until the 14th century AD. This site had been lost until the 1980's when geological prospections rediscovered the ancient silver mine. The place, currently explored for zinc-ore, is the focus of attention of the archaeologists, the historians, and the geologists as well. Planned facilities will have a destructive impact on the old pits, the ore-dressing and ore-crushing areas, and on the old canals as well. The respective performance of the classical satellite data was compared for lithological and structural mapping. New ALOS AVNIR-2 and PALSAR data were also evaluated in the frame of a pilot project supported by both the European Space Agency (ESA) and the Japanese Space Agency (JAXA). The image data base provided a range of spatial resolution from 5 m for Spot-5 to 80 m for Landsat-MSS. Geomorphological aspects concern the mapping of regolith surfaces, old terraces and the analysis of the hydrographic network. Using the higher resolution DEM it is also possible to evaluate the surface of the elementary watersheds. Canals linked these watersheds to the ore-dressing areas. 3D-representation helps for a better understanding of mining area as a whole extended on about 5km from North to South. One important issue concerns the climate of the past: Where grew the trees necessary for the melting of the ore? What was the hydrological regime at that time? Field data combined with a detailed analysis of the ALOS and QuickBird images opened up new perspectives. Finally, places for future field prospections have been identified using multispectral remote sensing data, with a special emphasis on gossan areas.

1 ARCHAEOLOGICAL AND GEOLOGICAL SETTING

Jabali is located between Sana'a and Ma'rib in the Republic of Yemen (Figure 1, upper left insert). The area was mined for silver as early as the pre-Islamic period. Basically, Jabali is known as one of the most important silver mines of the Abbasid world (Robin, 1988; Benoit *et al*., 2003; Peli, 2006). In the 10th century AD, the famous Yemeni geographer, Al-Hamdani, described this place then named al-Radrad. It was precisely exploited from before the coming of Islam until the murder of the governor of Sana'a at the end of the 9th century AD (883 or 884 AD). However, new datings obtained by our team demonstrate that the mining activity occurred until the 14th century AD. According to Al-Hamdani, the village of al-Radrad (Jabali) was extensive and located in a watered valley where palm trees grew, the current wadi al-Khaniq. The mine was connected to southern Iraq by a road passing notably through al-Bahrayn and al-Basra (Peli and Téreygeol, 2007). This site had been completely lost until the early 1980's when geological prospections carried out by the French Geological Survey, the so-called B.R.G.M., rediscovered the ancient silver mine and opened up new perspectives for the mining activity of Yemen (Christmann *et al*., 1983).

At Jabali, the old workings cover up to 10ha (see point no1, Figures 1 and 2). Their irregular landforms follow the ore concentration morphology. This latter is crossed by many shafts, drifts, low chambers and large tunnels, which sometimes exceed 100m in length (Robin, 1988). Arab medieval metalworkers identified a zinc oxide, the so-called *tutyia*, that deposited on the walls of the furnaces during the smelting process (Peli and Téreygeol, 2007). But zinc production as a pure metal is not known before the 14th century in India, the 17th century in China and the 18th century in the West, where the isolation of metallic zinc has been achieved independently by several people. Therefore, the Jabali area is currently explored for zinc-ore. The deposit contains a geological resource estimated at 12.6 million tonnes of oxide ore, grading about 9% zinc, 1.2% lead and 68g/t silver. The mineralization located within Jurassic limestones and dolomites includes carbonates and oxides (smithsonite, hydrozincite, etc.). It should be noticed that silver is mainly related to sulfides, which are also represented, even less than oxides, by rare sphalerite and especially galena (Al Ganad *et al*., 1994).

The area is the focus of attention of the archaeologists, the historians, and the geologists as well (Benoit *et al*., 2003). Basically, for these three topics Jabali offers an exceptional setting. But the persistence of the site is now in question. Some of the planned facilities, particularly a large open pit located close to the major site (no1, Figures 1 and 2), will have a destructive impact on the old pits, the ore-dressing and ore-crushing areas, and especially on the old canals coming from the Jabal Salab, already damaged by the preliminary mining works carried out since the 1980's. Other archaeological remains and slag heaps located far from the mine itself, especially in the wadi al-Khaniq (sites no2 and 3, Figures 1 and 2), will be unaffected.

In such an arid area poorly covered by detailed topographic maps and aerial photographs, the use of remote sensing methods is particularly suitable. Preliminary results of the remote sensing investigations have been presented, based on multiscale data and the use of very high spatial resolution QuickBird data. They referred to the archaeological (Deroin *et al.* 2006b) and geological setting (Deroin *et al.*, 2006a). We report here on the works in progress and particularly on the second interdisciplinary field mission carried out in February 2008.

2 REMOTE SENSING DATA

We have used a wide range of satellite data. These data were mainly obtained by optical sensors (LANDSAT, SPOT or ASTER), particularly interesting for their spectral response in the infrared range (700-2400nm). Some radar data have been also tested. Thus, we evaluated full-polarization ALOS-PALSAR data for estimating their ability to quantify the surface roughness of the regolith using their L-band (Deroin *et al.*, 2008). Whereas most of the rocky surfaces are sensitive to the VV polarization, it has been demonstrated that the wadi al-Khaniq, downstream the area of Jabali, is more sensitive to the HH polarization. In the field, these areas are characterized by flat modern alluvial deposits, some boulders and especially numerous shrubs. These trees offer large flat canopy sensitive to the horizontal component of the polarization (Figure 1, see the red areas corresponding to the near infrared response of the shrubs).

A multiscale analysis of the geological setting of Jabali has been hired including ALOS-AVNIR-2 data. It allows to recognize the regional extent of the geological units and tectonic features. At a larger scale, Landsat ETM+, Landsat TM and Spot panchromatic data have also been explored. Although relevant for geological mapping, the ground resolution from 10 to 30m is clearly too rough for detailed field investigations required by the geoarchaeological survey. Therefore, we used the pansharpening of very high resolution multispectral images from QuickBird with a 0.67 m ground resolution. The geological interpretation of these QuickBird data for the mine area results in a map representing 14 image-facies (Deroin *et al.*, 2006b). These latter could be easily correlated with the lithologies as observed in the field using their spectral and textural characteristics.

From an archaeological point of view, the QuickBird data drapped over a high resolution DEM (5m) allow to quantify the elementary watershed used for concentrating the water necessary to supply the ore-dressing areas (Figure 2). The work has been complemented in the field by GPS measurements of the old canals and their connection with the ore-dressing areas. Some of them have been already destroyed, but it is expected that the satellite data could allow to detect specific landforms. Other works concerning the accuracy of the spatial data are still in progress.

3 DISCUSSION-CONCLUSION

Teleanalytical geological mapping is a powerful method to analyse and interpret the geological setting of a poorly-known region. During this study, new geological topics have been pointed out such as the setting of the Jabal Amrah magmatic body, the extent of Zn-Pb-Ag mineralizations, the mapping of Quaternary terraces along the Wadi al-Khaniq or the detailed cartography of (de)dolomitization phenomena. Among the set of available sensors, the ALOS-AVNIR-2 sensor with its 10m-ground resolution and its visible-near infrared range appears as a good compromise for classical geological mapping at 1:50,000, complementary to the widespread large-scale LANDSAT imagery and to the higher resolution data (for example QuickBird or SPOT 5).

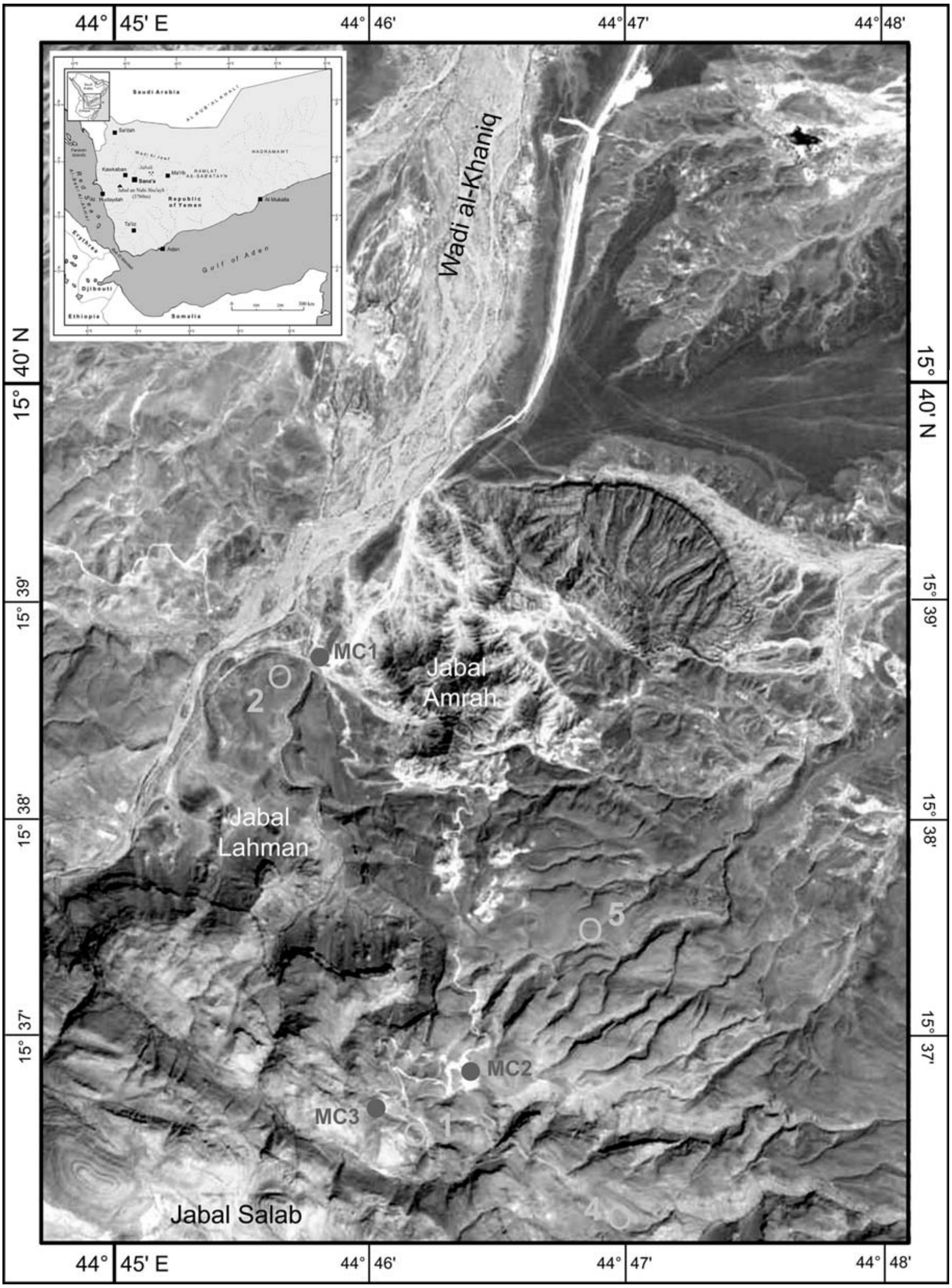


Figure 1. The Jabali area. False colour composite from ALOS-AVNIR-2 data acquired on 18 October 2006 (spatial resolution is 10 m). ALOS ADEN project no3643 (JAXA-ESA). The blue tones correspond to Jurassic carbonates affected by the thermal metamorphism due to the Jabal Amrah magmatic body's emplacement. The yellow to beige tones in the lower left corner correspond to dolomite and dedolomitized carbonates (Jabal Salab). The yellow circles indicate the archaeological places: 1.Jabali major site: Mines, ore dressing and crushing areas, canals. 2.Plateau with building remains, close to the wadi. 3.Wadi al-Khaniq rich in slag heaps. 4.Shutayba. Old mines and slag heaps. 5.Souk. Old mines. The green circles indicate the military camps of the National Guard of Yemen (MC).

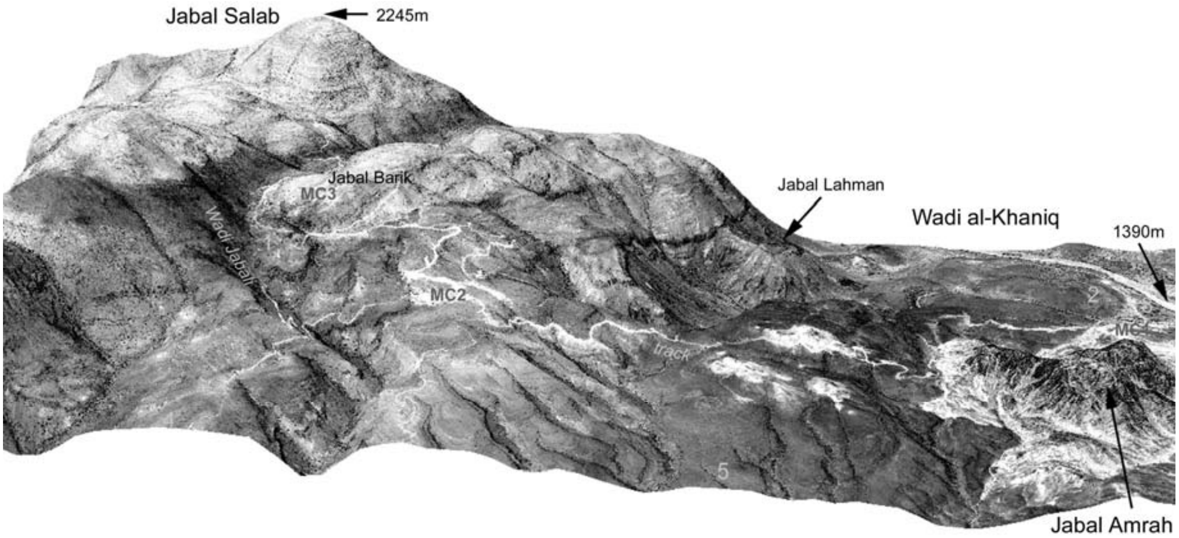


Figure 2. The QuickBird image acquired on 30 March 2002, drapped over the digital elevation model extracted from the 1:50,000 scale topographic map of Yemen (data: Deutsches Bergbau Museum). The yellow numbers refer to the archaeological places described in figure 1.

One major issue concerns the climate of the past: Where grew the trees necessary for the melting of the ore? Al-Hamdani mentioned 400 furnaces and the slag heaps cover more than 70ha (Benoit *et al.*, 2003). Moreover, the mineral extracted from the mine was washed to separate ore from the gangue, an operation that requires a large amount of water drained from the local watersheds. Therefore, the hydrological regime (precipitation, run-off, palaeocourses of the wadis) and the landscape as well were clearly different from the current ones. Thus, field data and the detailed analysis of ALOS and QuickBird images opened up promising perspectives. New places for future field prospections have been identified using remote sensing data. We have particularly recognized new gossans (iron caps) to the south-east of Jabali owing to the specific spectral reflectance of the iron oxides in the red range.

ACKNOWLEDGEMENT. The field missions have been facilitated by Mr Brett Grist, ZincOx, Sana’a Office, the Yemen Geological Survey and Mineral Board, and the French Ministry for Foreign Affairs. We are also indebted to Major Khaled Al Naphani and the National Guard of Yemen for assistance with field work. The ALOS project (P.I. J.P.Deroin) including the Jabali test site is conducted under the agreement of ALOS ADEN AO 3643.

4 REFERENCES

Al Ganad, I., Lagny, P., Lescuyer, J.L., Ramboz, C., Touray, J.C. 1994. Jabali, a Zn-Pb-(Ag) carbonate-hosted deposit associated with Late Jurassic rifting in Yemen. *Mineralium Deposita*, 29: 44-56.

Benoit, P., Féraud, J., Micheau, F., Téreygeol, F. 2003. Nouvelles recherches sur la mine d’al-Jabali. *Chroniques yéménites*, 11: 47-66.

Christmann, P., Lagny, P., Lescuyer, J.L., Sharaf ad-Din, A. 1983. Résultats de trois années de prospection en République arabe du Yémen. Découverte du gisement de Jabali (Zn-Pb-Ag) dans la couverture jurassique. *Chroniques de la recherche minière*, 473: 25-38.

Deroin, J.P., Al-Ganad, I, Al-Thari, M. 2008. The importance of SAR frequency, polarization, and incident angle for mapping arid regions, the Jabali test site, Yemen, ALOS ADEN AO 3643. *Proceedings of the First ALOS PI Symposium*, Kyoto, Japan, 4p., DVDRom, ISBN 978-4-906653-04-1.

Deroin, J.P., Al-Ganad, I., Al-Thari, M., Benoit, P., Téreygeol F., Heckes, J., Hornschuch, A. 2006a. Cartographie géologique télé-analytique. Influence de la résolution spatiale. Application à la région de Kawkaban-Sana’a-Ma’rib (République du Yémen). *Photo-Interprétation*, 42 (3): 3-18 and 59-62.

Deroin, J.P., Téreygeol F., Benoit, P., Al-Thari, M., Al-Ganad, I., Heckes, J., Hornschuch, A., Peli, A., Pillault, S., Florsch, N. 2006b. Archaeological remote sensing in Yemen, the Jabali test site. From large-scale survey to field investigation. *In* Campana S., Forte M., *British Archaeological Reports, BAR International Series,* 1568: 7-12.

Peli, A. 2006. Les mines de la péninsule Arabique d’après les auteurs arabes (VIIe-XIIe siècles). *Chroniques yéménites*, 13: 29-57.

Peli, A., Téreygeol, F. 2007. Al-Radrad (al-Jabali): a Yemeni silver mine, first results of the French mission (2006). *Proceedings of the Seminar for Arabian Studies*, 37: 187-200.

Robin, C. 1988. The mine of ar-Radrad: al-Hamdani and the Silver of the Yemen. In: *Yemen. 3000 Years of Art and Civilization in Arabia Felix*, Edit. W. Daum, Innsbruck, Pinguin, 123-124.

Data fusion techniques for supporting and improving satellite-based archaeological research

B. Aiazzi[1] , L. Alparone[2], S. Baronti[3], R. Lasaponara[4], N. Masini[5]

1 *CNR-IFAC, Via Madonna del Piano 10, 50019 Sesto F.no, Italy; E-mail: b.aiazzi@ifac.cnr.it*
2 *DET-UniFI, Via Santa Marta 3, 50139 Firenze, Italy; E-mail: alparone@lci.det.unifi.it*
3 *CNR-IFAC, Via Madonna del Piano 10, 50019 Sesto F.no, Italy; E-mail:* s.baronti@ifac.cnr.it
4 *CNR-IMAA, C.da S. Loja 85050 Tito Scalo (PZ), Italy. E-mail: lasaponara@imaa.cnr.it*
5 *CNR IBAM, C.da S. Loja 85050 Tito Scalo (PZ), Italy. E-mail:* *n.masini@ibam.cnr.it*

Keywords: archaeological mark, detection, image fusion, multi-resolution analysis, pan-sharpening, satellite remote sensing.

ABSTRACT: The increasing development of satellite remote sensing techniques and the growing availability of Very High Resolution (VHR) imagery, such as IKONOS or Quickbird (QB), makes satellite data useful not only for landscape archaeology and palaeoenvironmental studies, but also for the identification, management and documentation of archaeological resources. In such a context, satellite–based investigations may take advantage from the integration and synergic use of both satellite panchromatic and multi-spectral data. This can be achieved by using pan-sharpening techniques, which allow multi-spectral and panchromatic images to be merged. The two basic frameworks of pan-sharpening techniques are Component Substitution (CS), such as Intensity-Hue-Saturation (IHS) Gram-Schmidt (GS), and multi-resolution analysis (MRA) such as wavelets and Laplacian pyramids (LP). In this paper, both Gram-Schmidt and Laplacian pyramids with context adaptive (CA) detail injection models were used. QB images were processed for a relevant archaeological area in Southern Italy, the ancient Siris-Heraclea, a very significant test area because it is characterised by the presence of both surface and subsurface ancient remains. In our first investigations, the outcome of pan-sharpening has been qualitatively evaluated for both unearthed surface walls and subsurface remains. Preliminary results from the visual inspection suggest that the quantitative evaluation of the fusion performance for archaeological applications is a critical issue, and "ad hoc" local (i.e *context-adaptive*) indices need to be developed.

1. INTRODUCTION

In the last years, the availability of Very High Resolution (VHR) satellite data, such as IKONOS or QuickBird (QB), able to match with aerial photogrammetric images, has driven a great concern in the application of EO technologies to cultural and archaeology heritage. The increasing spatial and spectral resolution of satellite data makes the satellite images useful not only for landscape archaeology and palaeoenvironmental studies, but also for the identification, management and documentation of archaeological resources. From a rational point of view, the ability of satellite to detect surface or subsurface archaeological remains is largely determined by the image spatial resolution and their spectral capability. It is expected that the potentiality of VHR satellite data in detecting the subtle traces linked to the past human activities should be improved by using the data fusion techniques which enable the integration of the high spatial resolution of the panchromatic image with the spectral capability of multi-spectral images. This can allow us to achieve improved capabilities not possible with the individual datasets.

In this paper, different data fusion techniques were applied to a significant archaeological area Siris-Heraclea located between the Agri and Sinni rivers in Basilicata Region (Southern Italy) close to the Ionian coast. It is thought that the first settlement was related to the ancient Siris, that according to Strabon, was founded by refugees from Troy. Then the area was occupied by Greeks coming from Colophon, in Minor Asia. In the 6th century Siris was destroyed and in 433-432 B.C., a new town, named Heraclea, was founded by the Tarentines and Thurians. Today, the archaeological area is composed of two distinct parts, named high town ("Citta Alta") and low town ("Citta Bassa"). The distinction between high and low level is mainly due to a perspective visual impact, actually, both Città Alta and Città Bassa are at the sea level; their real difference in elevation is at around 20 m.

The "Città Bassa" is characterised by a spatial pattern of linear marks linked to the presence of subsurface remains, which provide a rough delineation of the ancient urban plan (A, Figure 1). Whereas, in the "Città Alta" remains of the Heraclea have been unearthed. In this study, both Citta Alta and in Città Bassa have been considered as test areas in order to assess the data fusion techniques for subsurface and surface remains, respectively.

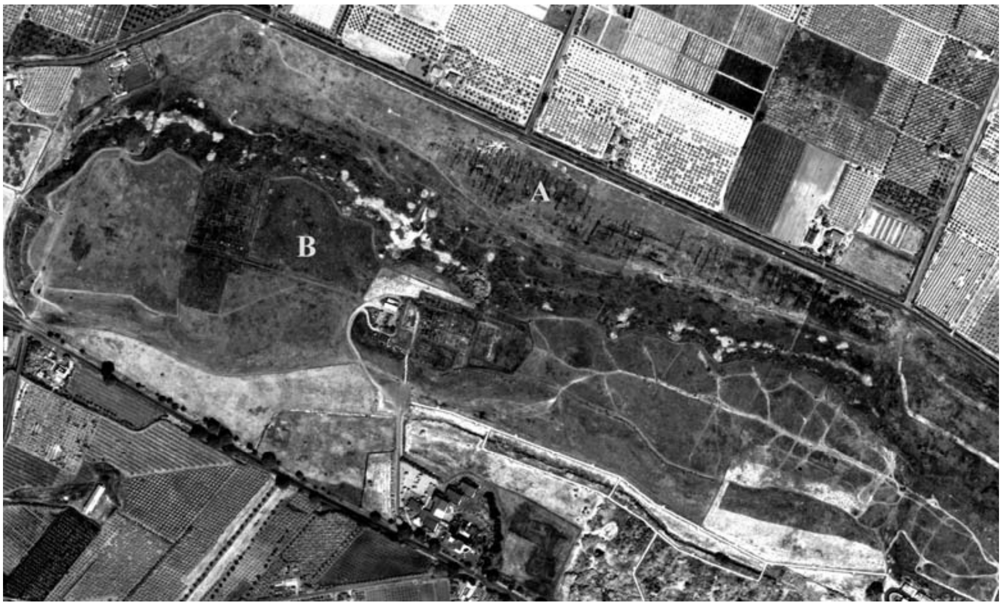


Figure 1. Study area. Letter A indicates the Citta alta*, letter B the* Città bassa.

2. PAN-SHARPENING TECHNIQUES

Pan-sharpening is a branch of data fusion that is receiving an ever increasing attention from the remote sensing community, since the availability of new-generation space-borne imaging sensors operating in a variety of ground scales and spectral bands provides huge volumes of data with complementary spatial and spectral resolutions. Thus, it is desirable to perform a spatial enhancement of the lower resolution multi-spectral (MS) data or, equivalently, to increase the spectral resolution of the data-set having a higher ground resolution, but a lower spectral resolution; as a limit case, constituted by a unique panchromatic image (Pan) bearing no spectral information.

To pursue this goal, an extensive number of methods have been proposed in the literature over the last two decades. Most of them follow a general protocol, that can be summarised as:

1) extract high-resolution geometrical information of the scene from the Pan image;

2) add such spatial details to the interpolated low-resolution MS bands through proper injection models.

In general, the image fusion methods described by this protocol can be divided into two main classes:

i) component substitution (CS) techniques, which are based on a spectral transformation of the MS data followed by substitution of the first transformed component with the Pan image and reverse transformation to yield back the sharpened MS bands;

ii) techniques that employ multi-resolution analysis (MRA) to extract from the Pan image the geometrical information that will be added to the MS bands.

CS-based methods are a typology of simple and fast pan-sharpening techniques based on a spectral transformation of the original bands in a new vector space. Most widely used transformations are Intensity-Hue-Saturation (IHS), Principal Components Analysis (PCA) and the Gram-Schmidt orthogonalisation procedure. Then, one of the transformed components (e.g. the intensity having low resolution, I_L) is *substituted* by the high-resolution Pan image, P_H, before the inverse transformation is applied. To ensure *global* preservation of radiometry, P_H is histogram-matched to I_L, in such a way that the histogram-matched sharpening Pan, once degraded to the spatial resolution of I_L, exhibits same mean and variance as I_L. However, since the histogram-matched Pan image and I_L may not have the same *local* radiometry, spectral distortion, appearing as local colour changes in a composition of three bands at a time, may occur in pan-sharpened products. It can be proven that this procedure is equivalent to *inject*, i.e. add, the difference between P_H and I_L into the interpolated MS data-set (Tu *et al.,* 2004). Therefore, IHS fusion technique, originally defined for three bands only, has been extended to an arbitrary number of spectral bands. To mitigate local spectral distortion, I_L may be taken as a linear combination of the MS bands with weighting coefficients adjusted to the extents of overlap between the spectral response of each MS channel and that of the Pan image. In principle, if the low-pass approximation of the Pan image synthesised by combining the spectral channels exactly matches the low-resolution version of P_H, spectral distortion does not occur (Tu *et al.,* 2004; Aiazzi *et al.*, 2007).

MRA-based techniques substantially split the spatial information of the MS bands and of the Pan image into a series of band-pass spatial frequency channels. The high frequency channels are inserted into the corresponding channels of the interpolated MS bands. The sharpened MS bands are synthesised from their new sets of spatial frequency channels. The "à trous" wavelet transform and the Laplacian pyramid are most widely used to perform the MRA (Núñez *et al.,* 1999; Aiazzi *et al.,* 2002). In such cases, the zero-mean high-frequency spatial details are simply given as the difference between P_H and its low-pass filter version P_L. The injection of the spatial details into the MS bands may be weighed by suitable gains, one for each band, possibly space-varying. Algorithms based on context adaptive models generally perform better than models fitting each band globally.

CS-based and MRA-based fusion techniques exhibit complementary spectral-spatial quality trade-off. The former provide fused images with high geometrical quality by possible spectral impairments. The latter are spectrally accurate in general, but may be unsatisfactory in terms of spatial enhancements. Eventually, MRA-based techniques are more sensitive than CS-based ones to spatial misalignments, i.e. shifts, between MS and Pan. Conversely, the latter are much more sensitive to temporal misalignments (MS and Pan acquired not at the same time), which may introduce severe spectral distortions.

3. QUICKBIRD PAN-SHARPENING FOR THE ARCHAEOLOGICAL REMAINS OF HERACLEA

Gram-Schmidt and Laplacian pyramids pan-sharpening methods were used for enhancing the ancient remains of Siris-Heraclea (Southern Italy). Satellite QB images were processed using both global and context adaptive (CA) injection models. In particular, three different algorithms, Gram-Schmidt (GS) (Laben & Brower, 2000), enhanced Gram-Schmidt (Aiazzi *et al.,* 2007) with context adaptivity (GSA) and generalised Laplacian pyramid with context adaptivity (GLP) (Aiazzi *et al.,* 2006) were applied. Figures 2 and 3 show details of data fusion from the three different pan-sharpening techniques obtained for (Fig. 2) the unearthed walls of the ancient Heraclea (Città Alta) and (Fig. 3) subsurface remains of the Città Bassa, respectively.

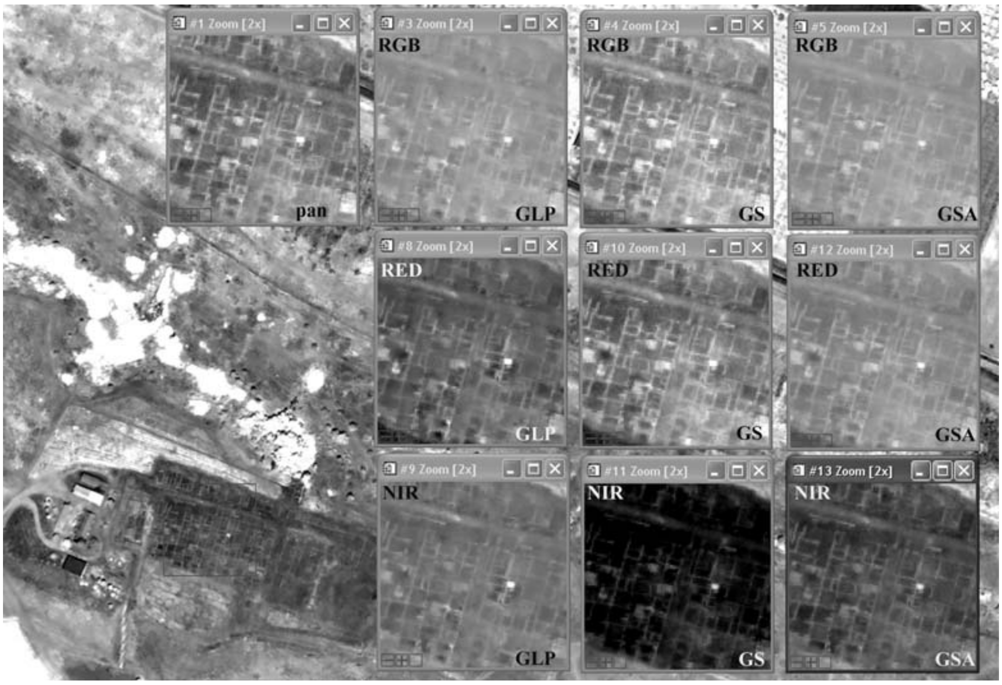


Figure 2. Results from data fusion techniques obtained from the test site related to surface remains in the Città Alta. Red square indicates the zoomed area

Both Figures 2 and 3 show the QB panchromatic scene, the RBG (R=Red, G= Green, B=Blue), Red and NIR data fusion products.

From a visual inspection of Figure 2 it is quite clear that in the case of unearthed wall remains the panchromatic retains most of the information due to the size of the walls which clearly delineate a regular linear pattern. The three different algorithms, GLP, GS and GSA, provide similar results.

Figure 3 shows the QB panchromatic scene and the same data fusion products as in Figure 2. A visual inspection of the zoomed area in Figure 3 shows that in the case of subsurface remains the results of the three different algorithms are quite different. As an example, details of the zoomed archaeological features indicated in the panchromatic scene with black arrows are sharpen with different characteristic in the NIR products. GSA better retains the spatial and spectral details of the archaeological features compared to the NIR products from GLP and GS. It is interesting to note that the spatial anomaly is less evident in GLP and appears to be broadened in the GSA and GS fusion NIR data products.

The fact that the NIR is the spectral band much more able to emphasise the archaeological features is not surprising and it is dependent on the type and characteristic of the investigated surface.

Of course the visual inspection is not enough to evaluate the results from the three considered pan-sharpening techniques. It is mandatory to numerically evaluate performance/benefits of different algorithms using adequate scores. Nevertheless, the visual evaluation we performed suggest that, in the case of data fusion for archaeological applications the numerical evaluation is a critical issue, since the performance obtained for the whole scene can not be significant for archaeological features. The different results we obtained in the case of unearthed surface walls and subsurface remains strongly confirm that a local ("context" adaptive) assessment needs to be developed.

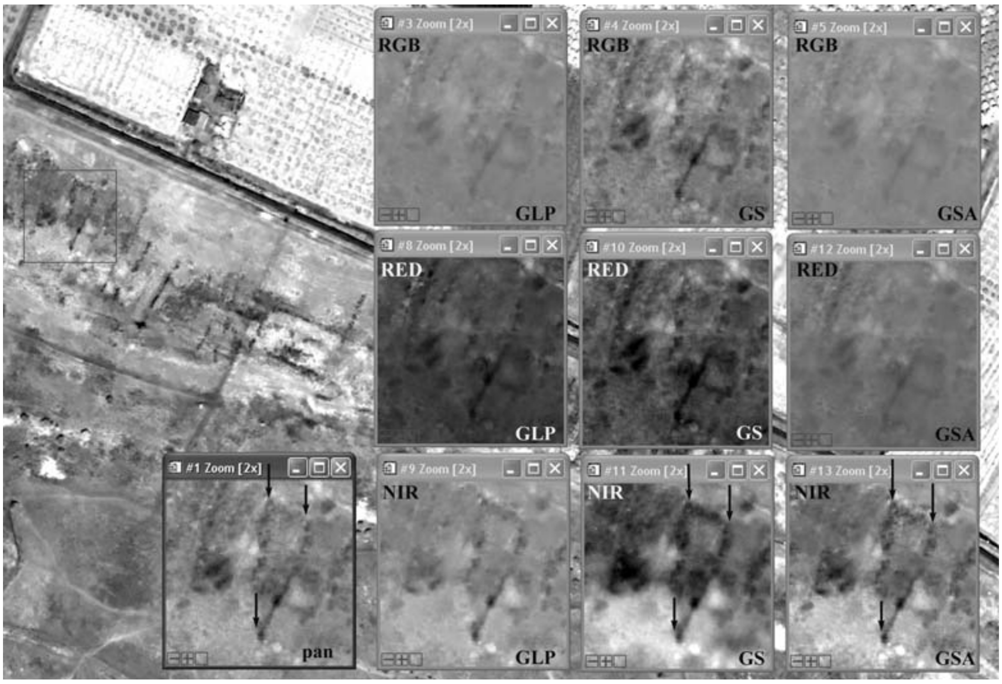


Figure 3. Results from data fusion techniques obtained from the test site related to subsurface remains in the Città Bassa. Red square indicates the zoomed area

4. REFERENCES

Aiazzi, B., Alparone, L., Baronti, S., Garzelli, A. 2002. Context-driven fusion of high spatial and spectral resolution data based on oversampled multiresolution analysis, *IEEE Transactions on Geoscience and Remote Sensing*, 40(10): 2300-2312.

Aiazzi, B., Alparone, Baronti, S., Garzelli, A., Selva M. 2006. MTF-tailored multiscale fusion of high-resolution MS and Pan imagery, *Photogrammetric Engineering and Remote Sensing*, 72(5): 591–596.

Aiazzi, B., Baronti, S., Selva, M. 2007. Improving component substitution pansharpening through multivariate regression of MS+PAN data. *IEEE Transactions on Geoscience and Remote Sensing*, 45(10): 3230–3239.

Laben, C.A., Brower, B.V. Process for enhancing the spatial resolution of multispectral imagery using pan-sharpening, *US Patent # 6,011,875*, Eastman Kodak Company, 2000.

Núñez, J., Otazu, X., Fors, O., Prades, A., Palà, V., Arbiol, R. 1999. Multiresolution-based image fusion with additive wavelet decomposition, *IEEE Transactions on Geoscience and Remote Sensing*, 37(3):1204–1211.

Tu, T.-M., Huang, P.S., Hung, C.-L., Chang, C.P. 2004. A fast Intensity-Hue-Saturation fusion technique with spectral adjustment for IKONOS imagery, *IEEE Geoscience and Remote Sensing Letters*, 1(4): 309–312.

Vicus Costanziaci between land and sea: Remote Sensing applications for the detection of the lost islands in the Venetian Lagoon

A. Traviglia[1], D. Cottica[2], L. Fozzati[3]

1 Department of Antiquity and Near East Sciences, University Ca' Foscari of Venice, Venice, 30123, Italy, traviglia@unive.it
Department of Archaeology – ACL, University of Sydney, 2006, NSW, Australia, atraviglia@usyd.edu.au

2 Department of Antiquity and Near East Sciences, University Ca' Foscari of Venice, Venice, 30123, Italy, cottica@unive.it

3 Soprintendenza per i Beni Archeologici del Veneto; Department of Antiquity and Near East Sciences, University Ca' Foscari of Venice, Venice, 30123, Italy, archeo@unive.it

Keywords: Roman Landscapes, Venetian Lagoon, Costanziaco, aerial pictures, HR satellite images, Quickbird, Ikonos

ABSTRACT.

"Vicus Costanziaci" is a project for the recovery, protection and evaluation of the historical and archaeological heritage of Costanziaco, an ancient small group of islands in the Lagoon north of Venice, of which currently just two emerged strips survive, namely: the abandoned islands of S. Ariano and La Cura. The project is being co-directed by D. Cottica (University Ca' Foscari of Venice) in collaboration with the Superintendency of Archeological Heritage of Veneto.

Exploring the area lying between the mainland and the lagoon represents an important opportunity for reconstructing the history of Venice before the well known medieval city arose. Through survey and excavations of the Costanziaco area, the project aims to shed new light on early patterns of occupation in the Venetian Lagoon, that is the history of 'Venice before Venice', to explore the communication network between the mainland and the sea and to examine the evolution of settlements along the commercial routes of the Lagoon.

The particular environment of research, the Lagoon, makes necessary the close collaboration of archaeologists and scientists of differing expertise. Remote sensing (RS) in this case is critical for investigating the ancient extent of the lost islands.

1. THE RESEARCH CONTEXT

In recent years the University Ca' Foscari of Venice and the Superintendency of Archaeological Heritage of Veneto have been collaborating on common research projects aiming to investigate specific aspects of patterns of habitation in the Lagoon of Venice during the Roman period (Cottica et al, 2008). Recently, a new joint research project has been lauched, co-directed by D. Cottica (University of Venice) in collaboration with L. Fozzati and the Superintendency of Archeological Heritage of Veneto. The project focuses on the study and archaeological excavation of two abandoned islands in the northern part of the Venetian Lagoon. These are located in the area where the Medieval site of *vicus Costanziacus* (currently named Costanziaco) is supposed to have existed on the basis of documentary evidence. At present the site is almost completely submerged: today of the ancient group of islands that formed *Costanziacus* only two strips of land still survive. These are the abandoned islands of Sant'Ariano and La Cura.

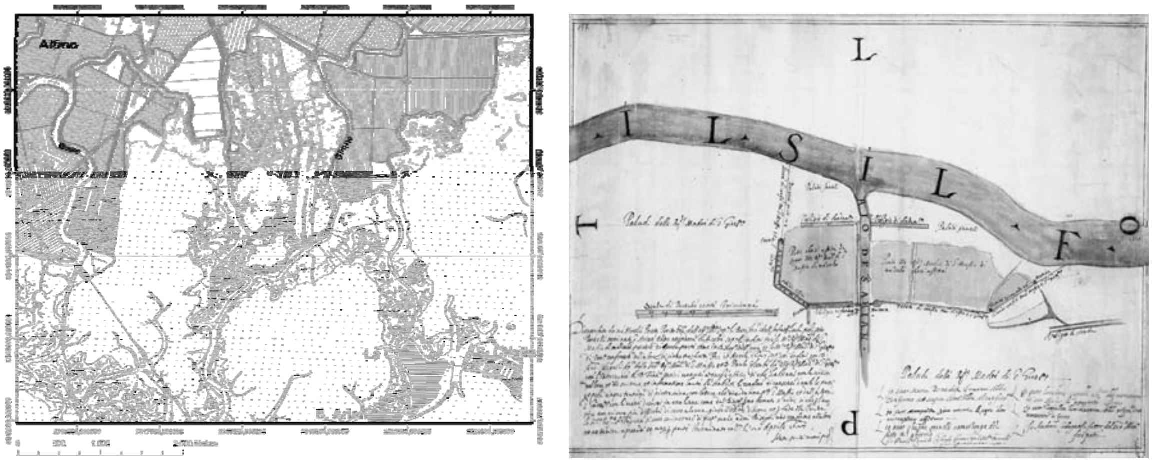


Figure 1: (left) the case study area and its relationship to the mainland; (right) map (Peretti 1627) representing the swamp lands close to Sile River, on the shores of the canal of S. Arian. The area corresponds to part of the ancient Costancianus Major (from Canal 1998, ASVE, Misc. Maps, drawing n. 197).

Former Costanziaco originally had a much larger extension: according to documentary sources it consisted of four islands clustered in two groups mentioned as *Major* and *Minor Costancianus*, which were located respectively on the right and left shore of the former river Sile, towards the mainland fringe of the Lagoon (Fig.1, right).

In the past, the lack of specific research and of direct archaeological investigation has kept the importance of this island underestimated within the economical, cultural and social framework of the Venetian Lagoon. Usually the history of the origin of Venice has been made coincident with the history of the nearby Torcello Island (Vecchi, 1982) and it is often associated with the migration of the inhabitants of the mainland toward the North Lagoon, under the pressure of the barbarians during the 5th century CE. However, several studies have made clear that before that period the geo-morphologic state of the Lagoon was suitable for settlement. Moreover Costancianus was situated in the proximity of an endolittoral watercourse connecting the mainland, the North Adriatic Sea and the Lagoon with the Roman port of Altinum (Scarfì & Tombolani, 1987). In this same area some Medieval ecclesiastic buildings were once located: these, according to some scholars, may have overlaid former settlements dating to the Roman period[1]. Interestingly, inland and underwater surveys carried out previously on Sant'Ariano and La Cura islands and in the surrounding shallows brought to light Roman and Late Antique finds, some of which date back to the early Empire (Fig. 2).

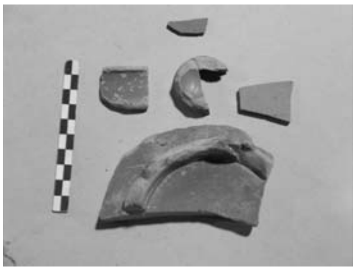


Figure 2. Shreds of Terra Sigillata from S. Ariano (image by D. Cottica).

Exploring the area between the ancient Roman town of Altino, on the mainland of the Veneto Region, and the island of Torcello in the Lagoon, represents an important opportunity for reconstructing the history of 'Venice before Venice'. Through survey and archaeological excavations, the project aims to bring new evidence to light and provide an amplified perspective on the question of the origins of the city of Venice. Furthermore, it will also add useful details to the study of routes, exchange and communication networks between the mainland, the Adriatic Sea and the Mediterranean.

---

[1] Dorigo 1994, p. 53. For general information about Roman presence in the Venetian Lagoon see Dorigo 1983 and Dorigo 1995. With regard to the navigation within the Lagoon in the Roman period see Fozzati & Toniolo 1998 and D'Agostino & Medas 2005.

2. AN RS ORIENTED APPROACH TO THE RESEARCH

The project foresees the use of field walking survey campaigns and stratigraphic excavations in the emerged, semi-submerged and underwater areas of the islands of S. Ariano and La Cura. The first field activities will take place during the summer of 2008, while the study of the archive documentation, the historical cartography, the remotely sensed data and the finds collected during past interventions in the two islands is already in progress.

The peculiar environment of research, the Lagoon, makes necessary the close and careful collaboration of land-based archaeologists, underwater archaeologists specialized in humid environments, and various scientific experts[2]. Remote sensing (RS) in this sense becomes critical to investigate the ancient extension of the lost island and to support the detection of archaeological traces both in the still-exposed land and in the submerged areas of barene (typical formations of the Venetian lagoon -shallows that emerge from the water during low tides and are covered by vegetation of brackish water-). RS will assist in the detection of the remains of the infrastructures and buildings of the ancient settlements, the former presence of which are suggested by historical sources and other archaeological finds. In previous archaeological impact assessment projects on the Lagoon of Venice, in fact, RS has proven to be quite efficient in the detection of archaeological features even in the submerged environment. Remotely sensed data will also provide crucial indicators for the identification of the areas that will be excavated during this and the next field season.

2.1 Available data and their processing.

Several types of RS data are being applied, including vertical and oblique pictures and satellite images3. Available aerial pictures range from historical oblique images to modern orthophotos, the coverage being very good including historical pictures from the 50s (IGM, Italian Military Geographic Institute) and almost one photographic survey from each year in the last ten years and around one every five years previously. The images are currently being processed through the use of the most common filters and stretches in order to emphasize certain characteristics that can improve the visibility of the traces.

The main focus however is put on High Resolution (HR) satellite images: Ikonos (2001, 2004 and 2007) and QuickBird (2003) scenes have been acquired and are currently under processing and analysis. Different processing techniques are adopted according to the different types of encountered environment (barene, land, lagoon waters etc.) including Vegetation Indices (NDVI, DVI, MSAVI2), Soil Index, Principal Component Analysis (PCA and SPCA) and band ratios. Focus will be on identifying from time to time those processes which best fit the goal of emphasizing features that can be related to the archaeological past of the islands.

From a methodological point of view, it is rather complex to predict the potential impact of the use of remotely sensed data for studying this portion of the Lagoon, considering the morphologic peculiarities of this type of eco-environmental context. Caution is due in the application of the remote sensing techniques since, in addition to the normal physic characteristics of a context that have to be kept in consideration -like soil use, pedology, climate and seasonal factors-, other phenomena, typical of the lagoon environment and able to generate peculiar situations, present themselves. Conditions like stress of the vegetation or increased humidity in bare soils in fact can distort and confuse interpretation, since they can result in manifestations similar to those indicating the presence underground of structures or of covered depression with possible archaeological nature. In this sense the constant consultation of environmental data, which makes the correct interpretation of the remotely identified features easier and whose consultation is guarantee through GIS, becomes fundamental.

The remotely sensed data are managed through a GIS that combines them with archaeological, topographical, hydrological data collected in the form of georeferenced datasets in order to support the interpretation of the detected traces. A systematic collection of published data was completed prior to the research and organized in the GIS platform in order to collect as much mapped or mappable information as possible for support in the disambiguation process of the traces detected in the remotely sensed data. Traces and anomalies identified on RS images are recorded by drawing them in apposite graphic layers of the geographical information system in order to be more easily compared with the information.

---

[2] At present the research team includes: A. Traviglia (GIS and Remote Sensing), D. Busato (archive and ancient cartography), P. Sfameni (excavation and survey), A. Toniolo (ceramicist) and M. Bon (archaeozoologist).

[3] The images have been provided by the Italian Ministry of Infrastructure – *Magistrato alle Acque* (*ConsorzioVenezia Nuova- Servizio Informativo*) in whose archive they are conserved and that the authors desire to thank for the collaboration.

3. CONCLUSIONS

The photo-interpretation process that will be performed during the 2008 research season will aim at the detection of the presence of possible surface traces (on vegetated areas or bare soil) or anomalies on the settlement distribution of the islands and of the surrounding lagoon area, which can be put in relationship with underground archaeological features.

The state of abandonment of the studied islands and the almost total inexistence of elevated structures that could obscure the investigated surface are ideal for investigation of photo-interpretation techniques, due to the prevalence of vegetated spaces or areas left uncultivated, which work as ideal "detectors" for the identification of the alterations on the surface caused by the presence of subterranean modifications. Ground truthing activities including field walking survey and excavation will follow in order to test the achieved results and define procedures that could be used in surrounding areas.

4. REFERENCES

Canal, E. 1998. *Testimonianze archeologiche nella Laguna di Venezia. L'età antica. Appunti di ricerca.* Venezia, Ed. del Vento

Cottica, D., Fozzati, L., Traviglia, A., Goti Vola, V., 2008. Nuove ricerche sulla Laguna di Venezia in età Romana, in Gelichi S. (Ed.), *Missioni archeologiche e progetti di ricerca e scavo dell'Università Ca' Foscari – Venezia.* Venezia, Cartotecnica veneziana, 151-158.

Dorigo, W. 1983. *Venezia. Origini. Fondamenti, ipotesi, metodi.* Milano, Electa.

Dorigo, W. 1994. *Venezie sepolte nella terra del Piave. Duemila anni fra il dolce e il salso*. Roma, Viella.

Dorigo, W. 1995. Fra il dolce e il salso: origini e sviluppo della civiltà lagunare, in Caniato G., Turri E., Zanetti M., Marzollo A. (Eds.), *La laguna di Venezia*. Verona, Cierre, 137-191.

Fozzati, L., Toniolo, A., 1998. Argini strade nella laguna di Venezia, in Pesavento Mattioli, S. (Ed.) *Bonifiche e drenaggi con anfore in epoca romana. Aspetti tecnici e topografici.* Modena, Panini, 197-208.

D'Agostino, M., Medas, S. 2005. La navigazione nella Laguna di Venezia in epoca romana: nuove evidenze dall'archeologia subacquea, *Rivista di Topografia Antica,* XV: 37-54.

Scarfì, B. M. & Tombolani, M. 1987. *Altino preromana e romana*, Altino, Comune di Quarto d'Altino.

Vecchi, M. 1982. *Torcello: nuove ricerche*, Roma, L'Erma di Bretscheneider.

Stereoscopic view, extracting DEM and cartography for archaeological purposes from Ikonos stereo pair: a case from Hierapolis of Phrygia territory (Turkey)

G. Di Giacomo[1], I. Ditaranto[2], G. Scardozzi[1]

1 CNR- IBAM. Italian National Research Council - Institute for Archaeological and Monumental Heritage, Strada per Monteroni c/o Campus Universitario, 73100, Lecce (Italy); digiacomogiacomo@yahoo.it, g.scardozzi@ibam.cnr.it

2 University of Salento, Department of Cultural Heritage, via D. Birago, 64, 73100, Lecce (Italy); immadit@hotmail.it

Keywords: archaeology, cartography, orthorectification, DEM, stereoscopic .

ABSTRACT.

This work analyses methods and problems connected with the elaboration of Ikonos stereo high-resolution satellite images to create a large scale cartography for the archaeological research. The paper show the case of Hierapolis of Phrygia (Turkey), where archaeological surveys, developed by the Italian Archaeological Mission, are in progress; particularly, this methodology has been used on an area (25 sq km) of the old territory of Hierapolis situated between modern villages of Yeniköy and Küçükdereköy, of which neither cartographies suitable for surveys on the ground nor aerophotogrammetrical covers were available. In this area there are many considerable archaeological presences particularly concerning an Hellenistic and Roman big village and its necropolises and an old Turkish destroyed settlement. An Ikonos stereo pair has been used to obtain a stereoscopic view of the entire area from where it would have been possible, after a data processing, to get a space map and to extract vectorial elements (modern topography, hydrology, archaeological evidences and traces, etc.) for the production of a cartography for archaeological research in the tolerances of a 1:10000 scale.

1 INTRODUCTION

Since 2003 archaeological surveys have been in progress in the urban area and in the territory surrounding the ancient city of Hierapolis of Phrygia, in south-western Turkey. The surveys are being performed as part of the research activities of the Italian Archaeological Mission (directed by prof. Francesco D'Andria), that since 1957 has been carrying out archaeological excavations and restorations in the city and in the surrounding large necropolises. The surveys were initially oriented towards the study of the urban layout and the necropolises; subsequently (2005) they were extended to cover the territory surrounding the city. The research project, still in progress, aims to cover a large area which in ancient times is believed to have been largely under the control of the city.

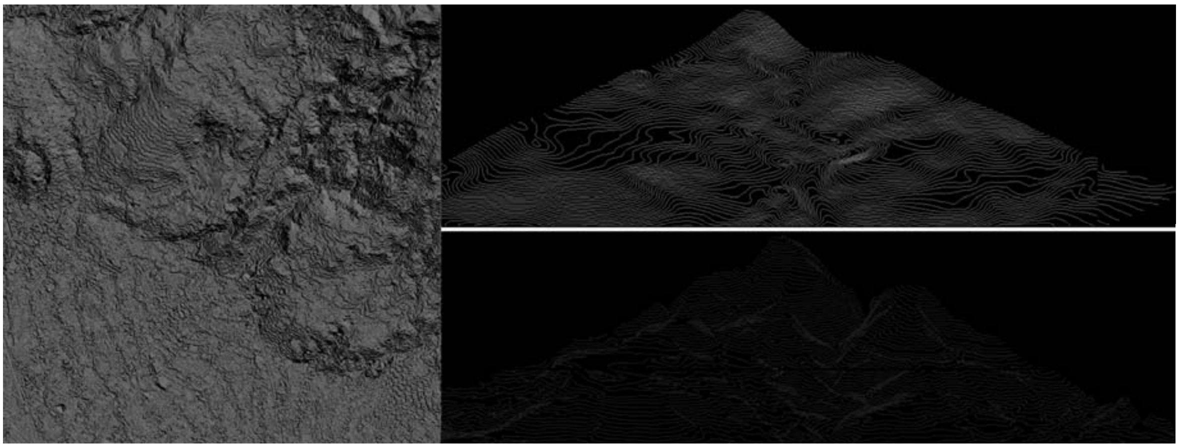
Ever since the first year of the research, extensive use has been made of high resolution satellite images (panchromatic and multispectral) provided by QuickBird-2, which have gone some way to compensating for the limited availability of aerial photographs and up-to-date maps on an adequate scale (D'Andria *et al.*, 2008, 25-30). The contribution of the satellite images to the research has been significant, since such images have provided constant support for the operations on the ground, both excavations and surveys; in fact, the interpretation of traces and anomalies resulting from buried or partly-emerging archaeological elements, duly verified on the ground, has enabled the identification and the spatial characterisation of archaeological evidences. So these images are used in all phases of the research: field work, data processing and management into the GIS of Hierapolis, and presentation of the results; particularly, they constitute one of the raster layers for positioning archaeological features and for vectorialization of traces and anomalies linked to ancient buried structures or paleo-enviromental elements.

For the surveys in the territory surrounding the city, satellite images have also compensated for the lack of up-to-date and adequate maps; in fact, the best topographical maps of the area are on a scale of 1:25000, and were drawn in the 1990s. These are suitable for an overview of the territory, but of little help in the field work. In the research, satellite images are not just a form of documentation complementary to the aerial photographs (they are read and interpreted before and during the field work, and during processing and interpretation of data), but they are orthorectified and constitute a basic tool for the direct exploration of the territory and for the recording and exact positioning of the ancient evidences. Particularly, the work presented here, analyses methods and problems connected with the elaboration of Ikonos-2 stereo high-resolution satellite images to create a large scale (1:10000) cartography for the archaeological research. The study was developed in a collaboration between the Institute for Archaeological and Monumental Heritage of the Italian National Research Council, the SIRTER company and the Chair of Archaeological Aerotopography of the University of the Salento (Prof. Giuseppe Ceraudo). The case study was focused on an area of 25 sq km situated about 2 km S-SE of Hierapolis, between modern villages of Yeniköy and Küçükdereköy. In this area, there are many and considerable archaeological presences, that particularly concern an Hellenistic and Roman big village and its necropolises and an old Turkish village, now destroyed: the lack of update cartography for surveys on the ground and of the aero-photogrammetrical covers made it necessary to create mapping with a suitable scale for the field work and for positioning archaeological elements into the GIS of the territory of Hierapolis.

2 CREATION OF SPACE-MAP AND CARTOGRAPHY FOR ARCHAEOLOGICAL PURPOSES

For this work was used a stereo pair captured on 24-04-2004 by satellite Ikonos-2 and distributed by Planetek company. The data processing was done by ENVI 4.4 and PCI Geomatica 10.0 softwares. The Ikonos images are panchromatic and multispettral, with four bands divided into four different files (Geo-Ortho Kit Bundle), and a dynamic range of 11-bit. With 11-bit of radiometric resolution, details in shadows, highlights, and low contrast scenes can be more easily discerned than in 8-bit images. Nominal collection elevation of stereo images used were 82.49 and 61.29 degrees; at the time of collection, geometric resolution of the first image was of 0.83 meters, the second was between 0.95 e 1.02 meters.

At the beginning of the research, the Ikonos panchromatic image with a smaller off-nadir angle has been orthorectified by DEMs, elaborated on the SRTM and ASTER data and by Rational Polynomial Coefficients (RPC) provided with the Ikonos stereo pair data; utilizing RPC to replace physical sensor models in photogrammetric mapping is becoming a standard way for economical and fast mapping from high-resolution images (Fig. 1). The geometric resolution, in fact, coupled with a proper geometric processing, enables the generation of products that can be compared with traditional cartography, even in scale 1:10000 (Tao, Hu & Croitoru, 2004). In the sensor camera modelling step, the goal is to construct the geometrical relationship between image space and three-dimensional ground space, so using ENVI, the relationship is modelled through rational polynomials. The next step was been the automatic collection of Tie Points that follows this procedure: it first extracts a number of evenly distributed distinct feature points from the left image, and then it applies them to an area-based through a matching technique to find their conjugate points in the right image taking, at the same time, any geometric distortions between the two images into account. A given point in one image and its conjugate point in the second image must lie on a known line in the second image. This knowledge can be used to create epipolar images, that are stereo pairs in which the left and right images are oriented so that ground features have the same y-coordinates on both images (Shippert & Zongxiang, 2006).



Figures 1-2. DEM derived from Ikonos stereo pair and two example of contour lines in 3D views, extracted from the DEM SRTM (in gray, with distance of 5 m) and vectorialized from the Turkish cartography with a scale of 1:25.000 (in blue, with a distance of 10 m).

DEM extracted from Ikonos stereo pair was extremely accurate, very good for the creation of a Digital Surface Model (DSM); this one, draped with satellite image, was used for 3D exploration of territory. For orthorectify processing of the image aimed to creation of cartography with a medium-large scale it is less good than DEMs extracted from SRTM data and from a stereo pair acquired from ASTER on 2004, with resolutions of 90 and 30 meters.

Generating DEMs from stereo data normally requires the use of a geometric model and ground control points (GCPs). The collection of GCPs presents a significant problem in many practical applications, as an existing source of GCPs may not be available. It is often prohibitively expensive to collect new points, especially for those areas inaccessible because of the road, or too impractical to acquire manually. A DEM generation method that requires no GCPs would be therefore of significant interest to users of stereo data. After a preliminary orthorectification of the Ikonos image without GCPs was created a space map (Fig. 3). Contour lines (with distance of 10 m) were vectorialized from the Turkish cartography in scale 1:25000. During the archaeological surveys on the ground we collected Ground Control Points and Check Points, both necessary to validate the accuracy of this orthorectification and a new orthorectification based on measured baselines. On the base of recent experiences in the carthographic production from high-resolution satellite images (see, for example, Baiocchi *et alii* 2004, Gianinetto & Scaioni 2004, Toutin 2004, Jacobsen 2006), the necessary vectorial elements for the production of a cartography in the tolerances of a 1:10000 scale right to the archaeological research have been extracted (Fig. 4) from the orthorectified image: many thematism were extracted like hydrography (little and seasonal river), fields, wooded areas, streets and country roads, modern houses and, finally, archaeological evidences and traces. We obtained a numerical cartography (still in progress) of an area of about 8,2 sq km, in conformity with the standard themes of the cartographic production: they are set in layers and the different homogeneous elements of the map follow a logical affinity; on this base, all the archaeological evidences detected on the ground have been georeferenced.

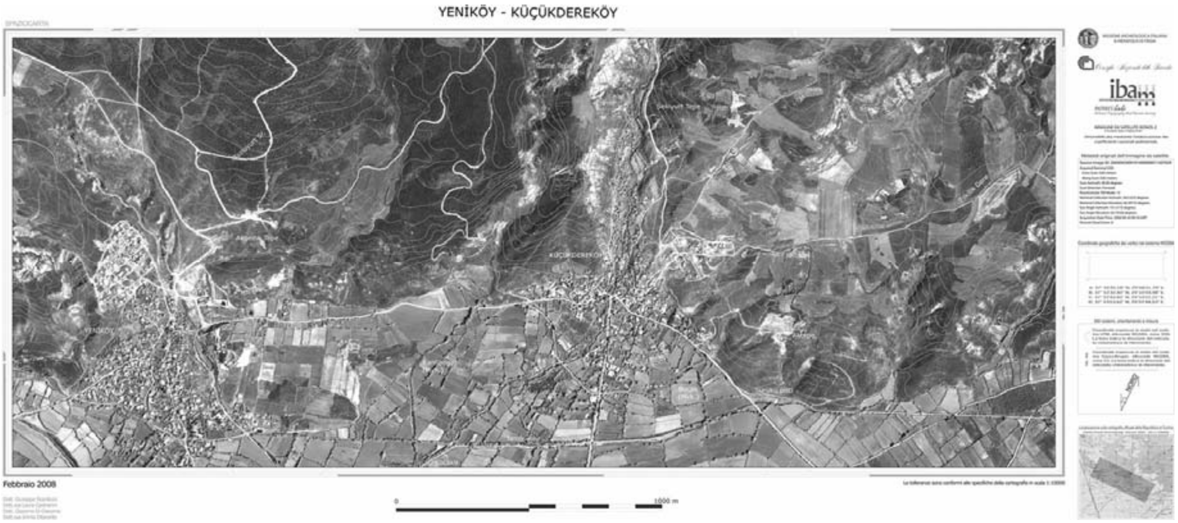
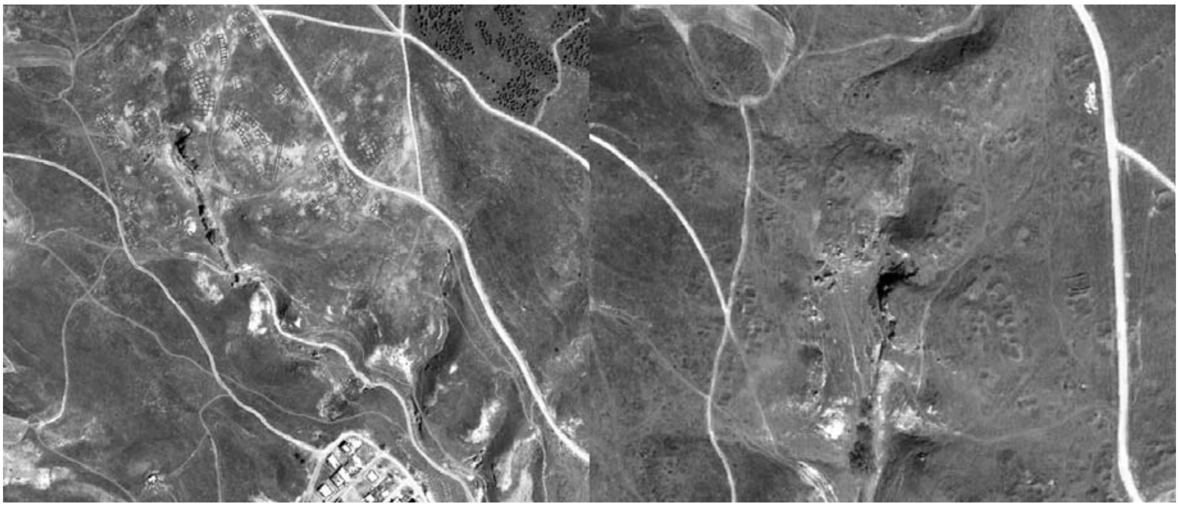


Figure 3. Space map created with an high resolution Ikonos-2 image in the tolerance of a 1:10.000 scale.

In every informatics layer of the cartography, the different entities have been indexed by univocal codes; this code was developed by the *Laboratorio di Topografia Antica e Fotogrammetria* of the University of Salento. During the restitution phase, the most possible correct and detailed way to represent morphology of the territory has been searched, so that information, in particular regarding altimetry, were legible: this aspect cannot be absolutely disregarded for the creating of a cartography dedicated to the archaeology. Moreover, this is valid firstly for traditional photogrammetry, as even a minimum difference can coincide with that in aero-archaeology is called micro-relief trace. On this subject, different methods have been compared for the creation of the contour lines: the vectorialization of contours lines with 10 meters interval of the Turkish cartography on scale 1:25000, used for the creation of the space-map; the extraction of contours lines with 1 and 5 meters interval from the DEMs obtained from Ikonos stereo pair, SRTM and ASTER data. The contour lines, deriving from the Turkish cartography, are obviously the same used as base of reference, since they are the only ones resulting from real measurements, while the others derive from an automatic process of extraction, though they come close to the real aspect of the studied territory. Ikonos stereo pair was also used to make the necessary epipolar images, getting so an anaglyph that became fundamental during the phase of the stereoscopic study of the area, also obtaining the restitution of the archaeological traces, in particular the micro relief ones.

Many archaeological evidences are partially visible on the ground and were documented during surveys; but a lot of traces of ancient elements, buried or partially buried were individuated during the study and the processing of the Ikonos images and of two QuickBird-2 images of 2005 and 2007 that cover a part of the study area; particularly, the research has relieved the presence of a big village of Hellenistic and Roman age, on which lies modern village of Küçükdereköy. Ancient settlement, perhaps under the control of Hierapolis, is situated to the slopes of the mountains that climb steeply toward the Küçükçokelz, in correspondence of a natural road of penetration that allowed to goes up from the Lycus valley to the plateau that threshold to the north the valley itself. Immediately to the south-east and above all to west, in direction of Yeniköy, are situated the necropolises, that have constituted prevalently by graves pit and few tumuli and *bomoì* sustaining sarcophagi in travertine. To the north of Yeniköy (in Turkish "new village"), also stretches the ruins of an old Turkish village ("Eskiköy", old village), almost completely destroyed, perhaps trims the ground from one of the many earthquakes that have struck the area. The ruins of the houses that cover a surface of about 25 hectares, in which has also reemployed architectural ancient elements, are with a square or rectangular plant and today appear partially buried. Poorly perceivable on the ground, they are well visible in the satellite images, that allowed the vectorial restitution of many structures.



Figures 4-5. An example of the cartography during restitution: in yellow are modern roads, in violet the paths, in blue modern houses and in red archaeological evidences (particularly, traces of an old Turkish village, now destroyed. A pan-sharpened QuickBird image of the Turkish village area with colour composite RGB 4-3-2: numerous traces of square and rectangular edifices collapsed are scarcely visible on ground.

3 ACKNOWLEDGEMENTS

For his constant support and the great interest with which he has followed the survey and archaeological research in the urban area and in the territory of Hierapolis, we thank Prof. Francesco D'Andria, Director of the Italian Archaeological Mission and of CNR-IBAM; special thanks also go to Dr. Laura Castrianni, who works on the survey research project from three years, taking care of the historic and archaeological aspects.

4 REFERENCES

D'Andria, F., Scardozzi, G., Spanò, A. 2008. *Atlante di Hierapolis di Frigia,* Istanbul.

Baiocchi, V., Crespi, M., De Vendictis, L., Giannone, F. 2004, *Ortorettificazione di immagini satellitari ad alta risoluzione per scopi cartografici: metodologie ed implementazione di un nuovo software*, *Boll. SIFET*, 1, 11-33.

Gianinetto, M., Scaioni, M. 2004. Estrazione di layer vettoriali per utilizzo cartografico da immagini satellitari ad alta risoluzione, *VII Conferenza Nazionale ASITA* (14-17 Dicembre 2004), Roma.

Jacobsen, K. 2006, *Comparison of photogrammetric applications based on narrow angle line scanners with traditional photogrammetric methods*, in Everaerts J. (ed.), *The future of remote sensing*, Second International Workshop (Antwerp, 17-18 October 2006).

Shippert, P., Zongxiang, Y. 2006. Extracting DEM's from stereo imagery, *GEOconnexion Intern. Magazine*: 26-27.

Tao, C.V., Hu, Y., Croitoru, A. 2004. Understanding the rational function model: methods and applications, *Proceedings of the XXth ISPRS Congress*, Istanbul 2004.

Toutin, T. 2004, Geometric processing of remote sensing images: models, algorithms and methods, *International Journal of Remote Sensing*, vol. 25 (10), 56: 1893-1924.

2

Aerial archaeology: from the historical photographs to multispectral and hyperspectral imagery.

The future of aerial archaeology (or are algorithms the answer?)

W.S. Hanson
Centre for Aerial Archaeology, Department of Archaeology, University of Glasgow, Glasgow, United Kingdom, G12 8QQ, E-mail: w.hanson@archaeology.gla.ac.uk

Keywords: aerial archaeology, bias, contextualisation, skills provision, methodological dichotomy.

ABSTRACT.

Four issues are highlighted in relation to the perceived undervaluing of aerial archaeology within the broader discipline of archaeology: potential bias within the methodology of data acquisition; the failure to contextualise aerial discoveries within wider archaeological understanding; the inadequate dissemination of aerial photographic awareness and skills among the wider archaeological community; and the methodological dichotomy between aerial archaeologists and airborne/satellite remote sensing specialists. Suggestions are made as to how each issue may be, or is being, addressed for the benefit of the discipline of archaeology as a whole.

1. INTRODUCTION

The impact of aerial photographic discoveries on British and European archaeology has already been immense, facilitating recognition of the density and complexity of settlement across the fertile lowlands over millennia and greatly extending the distribution of many site types. Nonetheless, it is the contention here that the potential of this approach to archaeological site discovery remains undervalued, underdeveloped and under threat.

I want to highlight four issues that need to be addressed if this situation is to be improved. These observations are based on many years experience as an aerial archaeologist and more recent utilisation of airborne and satellite imagery in both Britain and Romania. The issues to be considered are: potential bias within the methodology of aerial data acquisition and how that may be minimised; the failure adequately to contextualise aerial discoveries so that they more fully inform the wider understanding of the archaeology of a period or region; the inadequate dissemination of aerial photographic awareness and skills among the wider archaeological community; and the methodological dichotomy between aerial archaeologists and airborne/satellite remote sensing specialists.

2. BIAS

The primary mode of data acquisition in aerial archaeology has not changed since the origins of the technique in the late 1920s. The basic survey methodology employed still depends largely on observer directed flying generating oblique photographs (e.g. Wilson, 2000, 32-3). Apart from the problems that this generates in terms of producing measured plans from those photographs, the primary interpretation takes place in the air, not merely in terms of whether a particular feature is significant and should be recorded, but what flight path to follow during the reconnaissance. The serendipitous nature of the process is thus compounded, since not only might a site be missed because the observer was preoccupied, whether looking out of the opposite side of the aircraft or focussing on photographing other features, but whole areas can be overlooked because of the chosen flight path (e.g. Cowley, 2002). Anyone who has undertaken this form of survey will be further aware that what you see from the air, which triggers the recovery process, and what you see when you have the opportunity to peruse the photographic record in detail subsequently are not necessarily the same. The eye is drawn to the obvious patterns and can easily miss more ephemeral marks that become apparent on closer and more considered scrutiny of the photographs.

These problems have already been recognised (e.g. Palmer, 2005; 2007), but alternative more systematic approaches to data acquisition, primarily vertical block coverage, have yet to become standard practice in archaeological aerial reconnaissance, either because of concerns that such coverage is too expensive, too difficult to obtain or because the vertical viewpoint is perceived as less flexible and, therefore, less likely to be able to reveal some of the very slight nuances that constitute particularly cropmark evidence of past human activity (Wilson 2005). But such an approach to reconnaissance is simply unscientific, and can lead to the further reinforcement of biases which are inherent in the basic principles by which archaeological sites become visible from the air, which tend to favour particular regions or micro-climates (e.g. Hanson, 2005).

Alternative modes of data acquisition have long been available. Most obvious is consultation of archival vertical photography which potentially provides the required block coverage, but is not in most cases taken for archaeological purposes and may not, therefore, have been acquired in the best conditions for the recovery of cropmarks, soilmarks or even shadow sites. At least 15 million vertical photographs of Europe taken during and since WWII are currently housed in archives in Britain alone, largely uncatalogued in detail, such as The Aerial Reconnaissance Archive previously held in the University of Keele, but recently moved to RCAHMS in Edinburgh. Similar, if smaller archives, are known to exist in a number of other European countries, as well as the extensive European holdings of the National Archives and Records Administration in the USA. This is a much underused resource whose potential for archaeology has barely begun to be exploited (see Hanson and Oltean forthcoming), but which offers the opportunity to view the landscape in parts of Europe as it was over half a century ago before the impact of late 20th century industrialisation, with consequent greater survival and potential visibility of archaeological sites.

Historically, satellite data has been little used for archaeological purposes largely because of issues of ground resolution. Early, widely available imagery, such as SPOT or Landsat with a ground resolution of c. 15-20m at best, while helpful for land use assessment, was simply too coarse to aid in the recovery of archaeological data, though some use has been made of declassified Corona imagery which has a much better ground resolution of up to c. 2m (e.g. Oltean & Hanson, 2007; Philip *et al.,* 2005). More recently, however, with the launch of commercial satellites with a ground resolution of 1m or less for panchromatic or pan-sharpened imagery, such as Ikonos, Quickbird, WorldView and GeoEye, the potential has greatly increased (e.g. Beck *et al.,* 2007); all the more so as such imagery can be obtained, funding permitting, on demand on dates chosen by the purchaser. The regular use of such a resource should see the ultimate demise of traditional observer-directed archaeological aerial reconnaissance, except possibly for low light photography for extant ‘shadow’ sites, because of the sun-synchronous orbits of most satellites.

3. CONTEXTUALISATION

Despite concerns that current data recovery techniques are unsystematic and biased, the level of new discoveries has still far outstripped the capacity of the discipline to contextualise them. There is, therefore, a huge backlog of discoveries in national and local sites and monuments records offering substantial archaeological research potential.

Unfortunately, analysis and contextualisation of this material has not been keeping pace. The generation of maps as part of national mapping programme (NMP) of English Heritage, and to a lesser extent through RCAHMW in Wales, is highly laudable, but tends to be seen as an end in itself. With notable exceptions (e.g. Stoertz, 1997; Bewley, 1998), this data is not adequately being integrated within wider academic studies, whether thematic or chronological. Part of the problem lies in the location of expertise, which resides for the most part in national or local government agencies. Increasingly, those involved in reconnaissance and mapping do not have the time or the research priorities to pursue data analysis and to turn simple discovery and mapping into aerial archaeology by integrating the results into the wider interpretation of the historical development of the landscape. A good analogy is the generation of so-called ‘grey literature’ arising from commercial archaeological interventions, particularly excavation. It took a substantial research programme to begin to integrate that material into the consciousness of the wider archaeological community (Bradley, 2007). It is, therefore, unfortunate that University involvement in aerial archaeology in Britain is still limited. Even when the Cambridge University Committee for Aerial Photography was actively engaged in archaeological work, it focused primarily on data acquisition and presentation. Though aerial archaeology may be better represented in the University sector in other parts of Europe, notably in Italy, Austria, Slovenia and the Czech Republic, its results are still by no means fully integrated into the wider archaeological community, as the example of Poland well illustrates (Rączkowski, 2005).

Thus programmes of mapping aerial data remain fundamental, but are not enough in their own right. More synthesis integrating aerial and satellite data within a wider archaeological context is required to demonstrate its importance to the understanding of landscape history of all periods. Ideally such syntheses should also have some period focus, since many, arguably most, academic archaeologists are period specialists.

4. DISSEMINATION OF AERIAL PHOTOGRAPHIC AWARENESS AND SKILLS

Archaeologists need to be broadly familiar with a wide range of methodological approaches, but no one can specialise in them all. Aerial archaeology is no less a specialism than environmental archaeology, geophysical survey or finds analysis. While most archaeologists are fully aware of these techniques and what they can do, by no means all have the expertise to undertake research within these fields. As noted already, in the United Kingdom the expertise in aerial archaeology resides for the most part in national or local government agencies, such as English Heritage (formerly RCHME) and the Royal Commission on the Ancient and Historical Monuments of Scotland, or in the commercial or freelance sector. Surprisingly few aerial archaeology specialists seem currently to be found in the British University sector. Of the 164 members of the Aerial Archaeology Research Group (AARG), only 9 are British University based, representing only 6 institutions. Similarly, a recent survey of teaching provision for aerial archaeology in Britain undertaken independently by Dr. Peter Halkon of Hull University elicited responses from only 10 University Departments, suggesting relatively limited coverage of the subject in current courses (information kindly supplied by Dr. Halkon). A similar review of German Universities indicated that aerial archaeology was taught regularly in only two institutions, with six others providing some limited coverage as part of general survey courses (information kindly supplied Dr. Susanne Gerhardt). If the topic is not being researched and taught widely across the University sector in the United Kingdom, which has traditionally been at the forefront in the development of the techniques of aerial archaeology in Europe, or in Germany, then aerial photographic interpretational skills will continue to be the domain of the relatively few and the research potential of the vast resource of photographic data which has already been acquired not fully realised.

AARG, in conjunction with the *Europae Archaeologiae Consilium* (EAC), has already set in train a review of teaching and training provision in aerial archaeology across Europe with a view to making recommendations for promoting and enhancing teaching provision in order to address this perceived problem (http://www.e-a-c.org/12-0-Aerial-Archaeology.html).

5. METHODOLOGICAL DICHOTOMY BETWEEN AERIAL ARCHAEOLOGISTS AND SATELLITE REMOTE SENSING SPECIALISTS.

Satellite or airborne remote sensing specialists, with a background in the examination of large amounts of relatively low resolution data, address issues of archaeological site discovery from a very different perspective to the traditional approach of aerial archaeologists. In the first place they utilise multispectral or hyperspectral imagery as a norm, making full use of the wavelengths within the electromagnetic spectrum beyond those of visible light. In addition, the mathematical enhancement of imagery is standard practice, with the use of particular algorithms and the application of various filters, designed to aid in the interpretation of the data. Vegetation indices apply mathematical formula to express the particular spectral reflectance parameters of vegetation. Examples such as the Normalised Difference of Vegetation Index (NDVI), an index of variations in the vigour of green vegetation, have proven effective at enhancing archaeological cropmarks (e.g. Lasaponara & Masini, 2007). False colour composites, which map different band combinations to the three colour channels of a computer graphics system, facilitate production of an image focused on reflectance in particular parts of the spectrum, such as the near infrared, where the detection of variations in vegetation character may be enhanced (e.g. Aqdus *et al.,* 2007). The Tasselled cap mathematical transform, developed for use with Landsat imagery (Mather, 2004), uses a matrix of factors applied to the spectral bands to derive three new data layers highlighting greenness, wetness and brightness. Though the technique been little applied to the detection of archaeological remains, recent work has demonstrated its considerable potential (e.g. Challis *et al.,* 2008). The primary problem with all these approaches, however, is that the current resolution of multispectral and hyperspectral data, whether satellite or airborne based, does not yet approach that of panchromatic imagery, making identification of more ephemeral remains, such as cropmarks, more difficult.

Remote sensing specialists are often seeking more mechanical or automatic ways of extracting significance from the imagery, such as image classification, which attempts to correlate recorded spectra with real world phenomena using computer analysis to identify homogeneous clusters of pixels with distinctive spectral characteristics. Neither automatic/unsupervised classification nor supervised classification, based on ‘training’ a programme to locate areas with a particular spectral signature, have proved particularly effective for archaeological purposes, primarily because the spectral characteristics of archaeological objects are not sufficiently distinct from the general background. Thus Beck argues that it is contrast with the surrounding matrix rather than specific spectral signatures which help reveal archaeological sites (2007). It is generally recognised, therefore, that no single algorithm can detect all potential archaeological remains, so that a range of analytical techniques must be applied. Indeed, it is the very variability of archaeological traces which make them so difficult to decipher by means other than visual detection.

The latter is the traditional domain of the aerial archaeologist. The interpretation of, particularly, cropmarks is as much an art as a science. Thus, while the mathematical enhancement techniques of remote sensing can do much to enhance the visibility of anomalies within a growing crop, all the more so as we move to an era where satellite imagery becomes more common for archaeological reconnaissance, recognition of the potential archaeological significance of these anomalies will still depend on a base knowledge of the morphology of archaeological remains and the taphonomic processes which they undergo. Greater mutual appreciation of the relative contributions of what are currently sometimes diametrically opposed approaches to the same data sets on the part of aerial archaeologists and remote sensing specialists can only enhance the effectiveness and broaden the appreciation of the aerial perspective for the recovery of archaeological data.

6. REFERENCES

Aqdus, S. A., Hanson, W. S., Drummond, J. 2007. Finding archaeological cropmarks: a hyperspectral, approach, in Ehlers, M. and Michel, U. (eds) *Remote Sensing for Environmental Monitoring, GIS Applications, and Geology VII, Proceedings of SPIE Vol. 6749*, no. 674908.

Beck, A., Philip, G., Abdulkarim, M., Donoghue, D. 2007. Evaluation of Corona and Ikonos high resolution satellite imagery for archaeological prospection in western Syria, *Antiquity* 81: 161-175.

Beck, A. R. 2007. Archaeological site detection: the importance of contrast, *Proceedings of the 2007 RSPSOC conference, Newcastle upon Tyne* (http://www.ceg.ncl.ac.uk/rspsoc2007/papers/189.pdf).

Bewley, R. (ed.) 1998. *Lincolnshire's Archaeology from the Air*, Lincoln, Society for Lincolnshire History & Archaeology.

Bradley, R. 2007. *The Prehistory of Britain and Ireland,* Cambridge, Cambridge University Press.

Brophy, K., Cowley, D. (eds) 2005 *From the air: understanding aerial archaeology*, Stroud, Tempus.

Challis, K., Kincey, M., Howard, A.J. 2008. *Airborne Remote Sensing of Aggregate Landscapes, http://www.tvg.bham.ac.uk/alsf2008/5261_Report_Airborne_RS_of_Aggregate_Landscapes_v1_25_04_2008.pdf.*

Cowley, D.C. 2002. A case study in the analysis of patterns of aerial reconnaissance in a Lowland area of Southwest Scotland, *Archaeological Prospection* 9: 255-65.

Hanson, W.S. 2005. Sun, sand and see: creating bias in the archaeological record, in Brophy, K. and Cowley, D. (eds) *From the air: understanding aerial archaeology*, Stroud, Tempus, 73-85.

Hanson, W.S., Oltean, I.A. (eds) forthcoming *The spy in the sky: archaeology from aerial archives*, Cambridge, Cambridge University Press.

Lasaponara, R., Masini, N. 2007. Detection of archaeological cropmarks by using satellite Quickbird multispectral imagery. *Journal of Archaeological Science* 34: 214-221.

Mather, P.M. 2004. *Computer Processing of Remotely-Sensed Images*, Chichester, Wiley.

Oltean, I.A., Hanson, W.S. 2007. Reconstructing the archaeological landscape of Southern Dobrogea: integrating imagery, in Ehlers, M. and Michel, U. (eds) *Remote Sensing for Environmental Monitoring, GIS Applications, and Geology VII, Proceedings of SPIE Vol. 6749*, no. 674906.

Palmer, R. 2005. If they used their own photographs they wouldn't take them like that, in Brophy and Cowley 2005, 94-116.

Palmer, R. 2007. Seventy-five years v. ninety minutes: implications of the 1996 Bedfordshire vertical aerial survey on our perception of clayland archaeology, in Mills, J and Palmer, R (eds) *Populating clay landscapes: recent advances in archaeology on difficult soils*, Stroud, Tempus, 88-103.

Philip, G., Donoghue, D. N. M., Beck, A. R., Galiatsatos, N. 2002. CORONA satellite photography: an archaeological application from the Middle East, *Antiquity* 76: 109-118.

Rączkowski, W. 2005 Tradition in power: vicious circle(s) of aerial survey in Poland, in Brophy and Cowley 2005, 151-67.

Stoertz, C. 1997. *Ancient landscapes of the Yorkshire Wolds: aerial photographic transcription and analysis*, Swindon, Royal Commission on the Historical Monuments of England.

Wilson, D.R. 2000. *Air photo interpretation for archaeologists* (2nd edn.), Stroud, Tempus.

Wilson, D.R. 2005. Vertical versus oblique photography, *AARGnews supplement 1: Festschrift dedicated to Rog Palmer on his 60th birthday*, 32-4.

7. ACKNOWLEDGEMENTS

My thanks to Drs. Anthony Beck, Kenny Brophy and Ioana Oltean for comments on a draft of this paper.

Aerial Archaeology in Italy. Recent research and future developments

G. Ceraudo

LabTAF - Department of Cultural Heritage, Salento University, Via Dalmazio Birago 64 – 73100 Lecce, giuseppe.ceraudo@unile.it

Keywords: Aerial Archaeology, Italy, Research, Developments

ABSTRACT.

The different archaeological research conducted in Italy in recent years with the help of aerial photography, offer the opportunity to return to talk about the importance of this fundamental instrument in topographical studies and to reiterate some basic concepts.

The aerotopographic researchs in Italy, started with G. Lugli in 1938, after a further development from the end of the 2nd World War onwards thanks to the studies of Italian and foreign archaeologists (F. Castagnoli, G. Schmiedt, D. Adamesteanu, J. Bradford), find their final consecration in the last decades of the last century and particularly in activities conducted by specific research laboratories of the University of Siena, Second University of Naples and the University of Lecce.

The Italian situation at the present, on account of the spreading of systematic aerial reconnaissance, oriented aerial shots and derived studies, is greatly developing. The change in the legislation with the abrogation, in December 2000, of the restrictive and anachronistic "Royal Decree" of 1939 about aerial recordings, which effectively prevented the free activities of aerial recordings to scholars, is to be considered as one of the most significant changes in our field, and opened also in Italy the frontiers of aimed low flights and of recordings of oblique pictures.

This led to the launch of a number of initiatives and interventions in some regions of our Country. This paper will try to present a synthesis of the current trends and future developments of the matter.

The archaeological researches led in these last years in Italy with the aid of the aerial photography, give the idea for talking about the importance of this fundamental tool to the topographical studies on the territory and to confirm some basic concepts of the subject.

The aerial topographic studies, officially started in our Country by G. Lugli in 1938 (Lugli, 1939), after a further development at the end of the Second World War thanks to the increasing availability of aerial photographic material and to the intuitions and ability of illustrious names of the Italian and foreigner archaeology (F. Castagnoli, G. Schmiedt, D. Adamesteanu, J. Bradford), find their definitive consecration in the last decades of the last century (Ceraudo, 2004), and particularly in the field of the finalized activities conducted by specific Laboratories of research in some University centres of excellence (University of Salento - Lecce; Second University of Naples; University of Siena).

With the intent to renew that seam of research, also without losing sight of the fundamental objectives of knowledge to be reached through the topographical investigation on the territory, it is necessary to reassert that this type of activity is inevitably supported by the consolidate techniques of direct investigation on the ground. In fact, one of the elements that best qualifies the "Ancient Topography" is the survey, integral and systematic (Guaitoli, 1999).

The limits and the merits of this instrument of investigation are, in reality, well known since long time to all those people who regularly operate in the sector. "New" different terminologies are added to the old wording, all, among other things, inherent in the concept and in the methodology of the topographical investigation on the territory, specific subject of the "ancient Topography", as landscape archaeology, field survey, total archaeology, unexceptionable terms by itself, perhaps more modern and charming, that are sign of the fact that there was the need to express a certain multiplicity of interventions on the territory; this multiplicity not always works out in an enrichment and in a precise definition, but sometimes it is symptom of the introduction of elements of confusion that, unfortunately, not always remain in a formal level, but at times risk to invest also the substance of the subject.

From the terminology, it is justified to deduce a certain confusion between the mean and the goal, or rather between the means of study and the instruments that are useful for the research and the scientific goals of the research itself, with an excess of evaluation or a contortion of the traditional instruments of investigation with which we have a custom by now secular. It is unusual to notice as in these last years, exactly for the archaeological research on the ground, can be individualized, in the bibliography of the sector, a great number of publications on the methodological aspects in comparison to specific contributions on the jobs and on the obtained results (Ceraudo, 2008).

The comparison, also in the different operational choices, remains fundamental to address the discussion turned to the demand of refinement and development, inherent in the scientific research.

The comparison is useful, concerning the last years, with foreign colleagues that since more time develop activity of aerial recognition and who have promoted and alimented the discussion and the comparison (memory of the meeting at the British School at Rome in December 2004) in a sector certainly limited in the field of action by restrictive normative, now fortunately abolished, but however always vital and dynamic (Musson *et al.*, 2005).

Among these "tools" also the use of the aerial photography has received a notable increase in the different directions: from one hand the areas interested to the experiences of archaeological photo interpretation are increased, from the other one the interest is accented for the cartographic representations of the territory, both as cartography of base - essential support for the knowledge and for the guardianship -, and as photogrammetry finalized to the archaeological use (Piccarreta, 1997; Ceraudo, 1999).

From the methodological point of view, I continue to be convinced that the use of the aerial photography must be tightly tied to the primary demand of contextualization and topographical position of the find - trace - and to its precise survey. The phase of the design, which is the action to fix in the space and in this case to return on the map (cartographic positioning) a defined object, even if in trace, constitutes the essential presupposition for the knowledge and for the guardianship of the cultural heritage. In the specific case of the archaeological traces, even though read, interpreted and described, but not put into a graphical design with aerial photogrammetric restitution, they would remain an abstract element, uprooted from the context, only a moment of passage in the research of a determined territory, on which it would be however impossible to effect exhaustive studies or to practice an any action of guardianship.

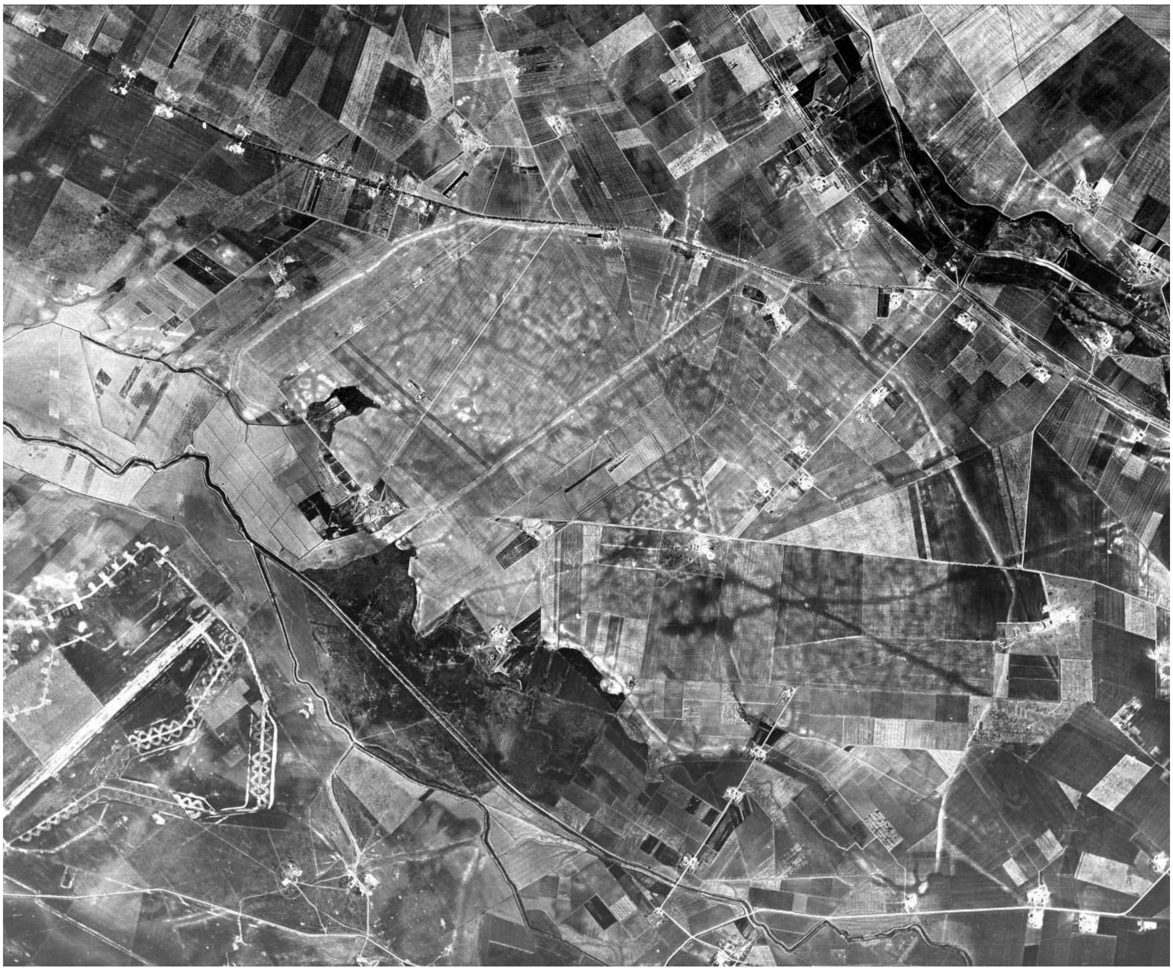


Figure 1. A vertical air-photo from 1957 showing the area of the ancient settlement of Arpi (Foggia).

For all these reasons, the consolidated use in Italy of vertical aerial images (figure 1), photogrammetric type, was not and is not, also to the light of the change of the law, a shift, it was, rather, and it remains, a point of strength, a fundamental passage of the research in the studies of "archaeological aerial topography", to combine to the cartographic restitution (Piccarreta & Ceraudo, 2000).

I believe that the optimal employment of this precious instrument, as we are doing within the activities of the

LabTAF (on the ancient centres of Veio, Aquino, Arpi (figures 2-4) only to quote those in a more advanced phase of study), is to integrate the sources, to associate to the activity of aerial recognition, and therefore in the case of individualization through oblique photographs to low quota of archaeological traces, a following flight for the execution of aero photographic and planimetric stripe, of photogrammetric kind, that allows a punctual restitution and contextualization of the ancient individualized elements, above all allowing to avoid complex passages of straightening and correction of the oblique images with the representation of the traces often problematic and rather inaccurate.

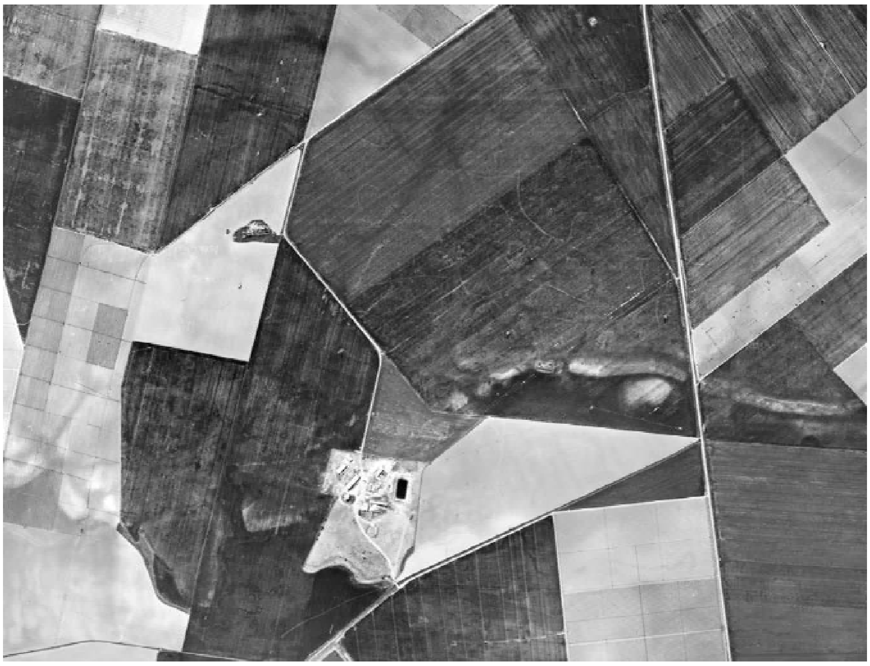
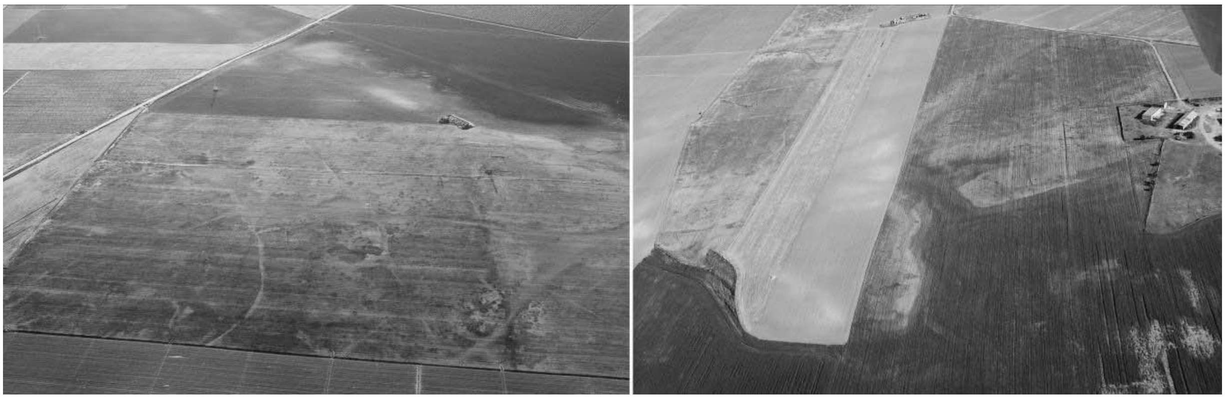


Figure 2. Part of a vertical air-photo from 1997. The image shows the remarkable cropmark of the 'aggere' and of ancient roads within the urban area of Arpi (Foggia).

It is obvious that the elaborated data by the reading of the aerial photographs (vertical and oblique, historical and recent), in the specific case of the archaeological traces, obligatorily attend a punctual check on the ground to be able to pass from the level of generic indication to that of archaeological evidence to all the effects: a presumed archaeological trace, seen on an aerial image, has necessarily to be connected to objective data, checkable only afterwards the direct verification on the ground by some experts of the subject.



Figures 3 – 4. Oblique air-photos showing several cropmark of the ancient roads (left) and of the 'aggere' (right).

Even if the digital image seems to bossily set out to be the only tool to be exploited, the existence of an enormous quantity of traditional aerial images on film, a lot of them still "unpublished", preserved in the aerial photographic archives and still to be read and elaborated, makes essential the maintenance of procedures and the "know how" necessary to accomplishedly extract the data in them contained.

REFERENCES

Ceraudo, G. 1999. *Introduzione all'aerofotogrammetria applicata all'archeologia*, Ponza, Il Grande Blu.

Ceraudo, G. 2004. Un secolo e un lustro di fotografia aerea archeologica in Italia (1899-2004). *Archeologia Aerea. Studi di Aerotopografia Archeologica,* I: 47-68, Roma.

Ceraudo, G. 2008. *Sulle tracce della Via Traiana. Indagini aerotopografiche da Aecae a Herdonia*, Foggia, Claudio Grenzi Editore.

Guaitoli, M. 1999, Appendice III. Nota sulla metodologia della raccolta, dell'elaborazione e della presentazione dei dati, in P. Tartara, *Torrimpietra (IGM 149 INO)*, *Forma Italiae* 39, Firenze, Leo S. Olschki Editore, 357-365.

Lugli, G. 1939. *Saggi di esplorazione archeologica a mezzo della fotografia aerea*, Roma.

Musson, C., Palmer R., Campana S. (eds.) 2005. *In volo nel passato. Aerofotografia e cartografia archeologica.* Firenze, All'Insegna del Giglio.

Piccarreta, F. 1997, *Fotogrammetria finalizzata all'archeologia*, in *Beni Archeologici Conoscenza e Tecnologia.* Quaderno 1.2, Lecce-Bari, Martano Editore – Edipuglia, 51-70.

Piccarreta, F., Ceraudo G. 2000. *Manuale di Aerofotografia Archeologica. Metodologia, tecniche e applicazioni*, Bari, Edipuglia.

Giacomo Boni: a pioneer of the archaeological aerial photography

L. Castrianni
University of Salento, Department of Cultural Heritage, D. Birago 64, Lecce, Italy. E-mail: scatarci15@virgilio.it

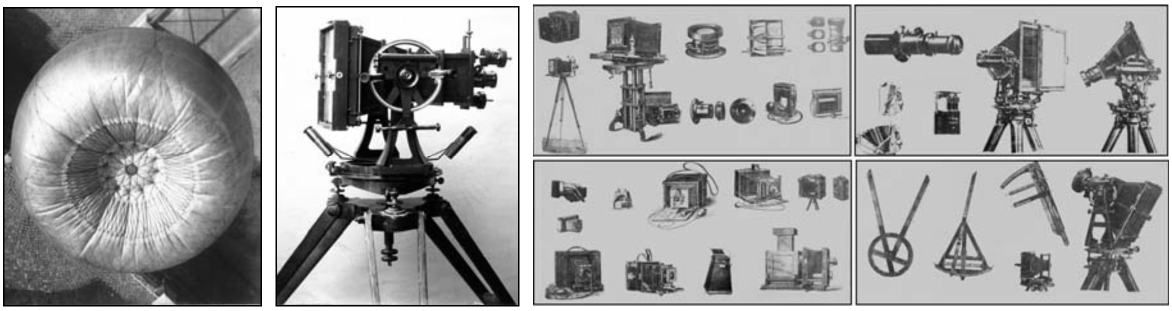
Keywords: archaeology, aerial photography, Giacomo Boni, Roman Forum, balloon

ABSTRACT: The main purpose of this work is to introduce the Giacomo Boni's experience as the first application of the aerial photography in the European archaeological research. The Venetian architect, entrusted in 1898 by the Minister of Education Guido Baccelli with the management of a new excavation campaign in the Roman Forum, used - for the first time - the contribution of this auxiliary science according to archaeology. Boni, from 1899 to 1909, carried out a series of ascents with a balloon offered by the Italian Engineering Military Corps, in order to create a planoaltimetric survey of the valley of the Roman Forum and to document the excavation work in progress that since 1907 also affected the Palatine Hill area. The aerial photographs, taken at different heights, till today represent an exceptional documentation of the progressive advancement of excavations (reports still widely unpublished). These documents are an indispensable instrument of study for the knowledge of the central archaeological area of Rome. Furthermore they are the first example of the use of this auxiliary instrument in archaeology and so, in my opinion, they raise to an important documentary value related to the techniques and the methodologies experimentally used, at the turning to the twentieth century.

The archaeological excavations of Giacomo Boni, undertaken in the Roman Forum in Rome during 1898, represent till today, after more than a century, a model to follow about the technical, scientific and methodological point of view (Capodiferro & Fortini, 2003). Boni, "*the good genius of the Roman Forum*", as the newspapers of the time called him, was a versatile man with multiple interests (*L'Illustrazione Italiana,* 1907; Iacopi, 2003). He became the promoter of several experiments which included the application of most of the diverse auxiliary sciences to archaeological research (Figures. 1-2-3).

Figures 1-2-3. Giacomo Boni posing in front of Tito's arc (from L'Illustrazione Italiana 1907*); aerial photographic survey of the Roman Forum with draken and spherical balloon (from* Tardivo, 1910; *L'Illustrazione Italiana,* 1900*).*

The importance given to graphical and photographic documentation of the excavation led the Venetian architect to try an enterprise never tried before: the realization of aero photography of the excavation area; shootings that were done by the Royal School of Engineering in Rome in order to obtain a photogrammetric survey of both the Forum and the Palatine Hill (Taviani, 2003). The result was, in Tardivo's words, "*the true portrait of the terrain*" (Tardivo, 1912).

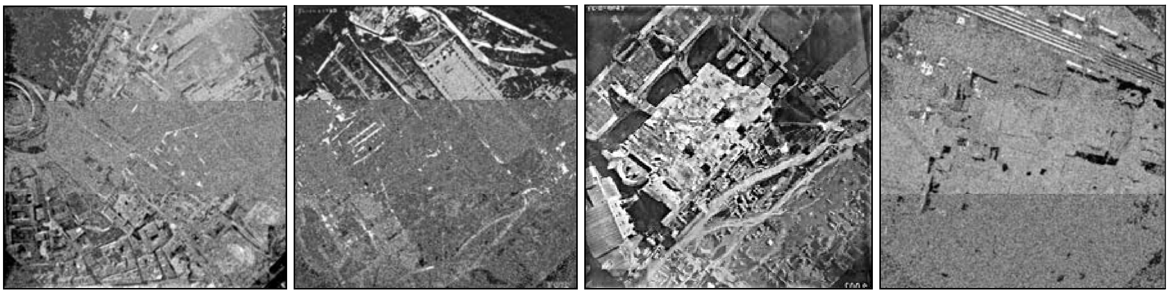


Figures 4-5-6. The self deforming balloon of the Lieutenant Ranza (from Ranza 1903*); the camera of the Captain Tardivo (from* Tardivo 1912*); the technique instrumentation used by the Section (from* Borgatti 1900*).*

The first aerial photographs of the Roman Forum are dated June 1899 (Tea, 1932; Lodi, 1981). They are the first aerial photographs examples in Europe. As we learn from Boni himself (Boni, 1900); they have been taken from a changing height between 300 and 500 meters above the sea level from a balloon borrowed by the 3rd Specialist Brigade of the Engineers Corps. It was just the first collaboration that would lead to the birth of aerial photography for archaeological purposes (Piccarreta & Ceraudo, 2000; Piccarreta, 2003; Ceraudo, 2004). In the successive decade, after this first photographic campaign, there were at least three further flights.

The photographic material produced in these campaigns, kept either in private and public - Italian and foreign - archives of Rome, is currently object of study of a team - led by Professor G. Ceraudo - composed by experts and researchers of the Laboratory of Ancient Topography and Photogrammetry (LabTAF) of the University of Salento, under the direction of Professor M. Guaitoli. The aim of the research – that avails of the collaboration of the Soprintendenza Speciale per i Beni Archeologici di Roma (SSBAR), in the person of Dr. P. Fortini, is to create a single and coherent *corpus* and to reach, starting from the bases of both internal and external data (archives and newspapers extracted from that period) the exact schedule of each of the photographic campaigns.

Aerial photography was not only the first application of a new technique applied to the archaeological research, but also gave a deeper knowledge of the not yet published history of the excavations of the Roman Forum and indirectly let to know the new techniques used - especially in the military field - and allowed it to have a further development in the following years (Lodi, 1961; Della Volpe, 1980; Chiusano & Saporiti, 1998) (Figures. 4-5-6).



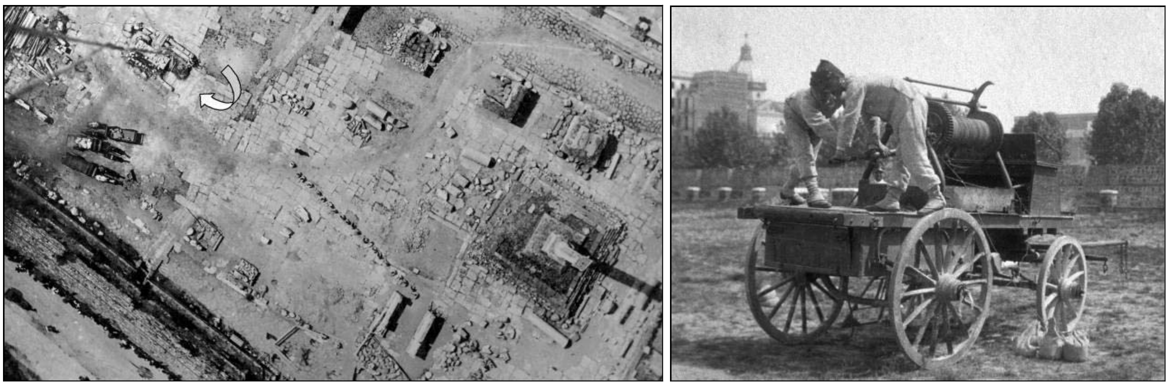
Figures 7-8-9-10. Some of the aerial photographs of the Roman Forum kept in ICCD; in them are visible, with different level of detail: the valley of the Forum, the Palatine Hill, the Massenzio Basilica and the central area of the Roman Forum (Photographic Archive ICCD, negs. 58093-58089-58088-58098).

The taken photographs show, at various levels of detail, the central archaeological area of Rome - in some of them besides the Roman Forum it is possible to see the Palatine Hill and the Coliseum. This gives us either general view of the excavations and an analytical look at the single monuments (figures 7-8-9-10).

Besides the object of the photograph we also have the main activities of the ballooners as well as their instruments, for example the manoeuvre trolley and the ropes, useful for the aerial shootings (figures 11-12).

These factors make the photographs a fundamental evidence of the practical job inspired by the same theoretical principles that were written in the first aerial photography and aerophotogrammetry manuals. Thanks to these manuals, it was possible to have a further understanding of the high level reached in the scientific innovation and technical experimentation by the pioneers of the Italian aeronautics at the beginning of the last century. Moreover, the awareness of the fundamental importance held by the archaeological application in those crucial years, had a huge growth. For example, it's emblematic, that the only table accompanying the illustration of the volume of Captain Tardivo (Tardivo, 1911) is a photomosaic of the area among the Coliseum and the Campidoglio (Figure 13), whereas three of the aerial views of the central archaeological area of Rome are taken as an example of raised photographs made at different scales of detail in the manual of the Lieutenant Ranza (Ranza, 1907).

The importance of such archaeological applications is also confirmed by the reports read by Tardivo in the international meetings of photography and photogrammetry that were held in Brussels and Vienna during the same years. During the introduction to the topographical activities of the Photographic Section of the Italian Engineering Military Corps, the archaeology led the main role, as demonstrated by the important case history of Rome, Pompeii (1910) and Ostia (1911). These are the fields of application that allowed our soldiers to spread the Italian military intelligence applied to the culture abroad.



Figures 11-12. Ballooners at work in the central area of the Roman Forum: in the upper right corner it's possible to see the ropes anchored to the ground (AAR Photographic Archive, neg. FU 3225); two ballooners are busy on winding the rope around the winch (from Ranza 1903).

It is possible to say that, at that time, a dual-link united the military environment to the Italian archaeological area: in fact, on one hand archaeology was the purpose for which the new techniques of aerial photographic survey were tested, on the other hand archaeology was used as a way to test the new military studies, in several different fields.

At the end, the cooperation established between Giacomo Boni and the Italian military environment, in particular Captain Maurizio Moris - Commander of the 3rd Specialist Brigade of the Italian Engineering Military Corps (Zicavo, 1928; Pesce, 1994) - gave birth, after few years, to the archaeological aerial photography in Italy and Europe. The exceptional nature of the enterprise, never attempted before, is well highlighted by the newspapers of the time, where it was possible to read that they "were able to achieve what was never done before", turning the Forum into a "place of pilgrimage for scholarships from all over the World" (*L'Illustrazione Italiana,* 1900).

From these words, it is possible to reconstruct the effect of the operations of photographic survey to the Roman Forum upon the public opinion of the time: an effect certainly wanted and wisely used by Boni, who exploited the almost constant attention reserved by the press to the actions of the Italian Engineering Military Corps in order to give further prestige to the activities of archaeological research that he was leading in the Forum. It is exactly thanks to the wise management of the communication led by the Director of the excavations at the Roman Forum, that most of the works have been followed by the main newspapers, either Italian and foreign, helping to the creation of an international echo around this important event and around its supporter too.

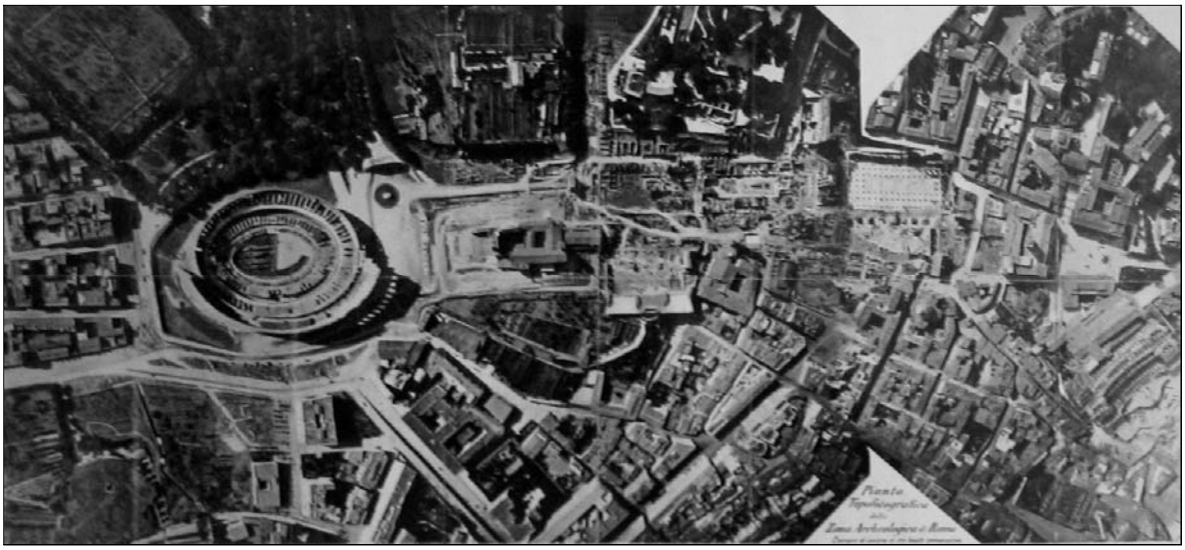


*Figure 13. "Topophotographic map of the Archaeological Area of Rome. Example of the union of three consecutive shots." (*Tardivo, 1911*, extra text panel).*

REFERENCES:

AAR. American Accademy at Rome.

ICCD. Istituto Centrale per il Catalogo e la Documentazione.

ISCAG. Istituto Storico e di Cultura dell'Arma del Genio.

Boni, G. 1900. Rilievo eseguito dalla R. Scuola d'Applicazione degli Ingegneri di Roma, nell'area compresa fra il Colosseo e il Tabularium, *Notizie degli Scavi di Antichità*: 220-229.

Borgatti, M. 1900. *La fotografia applicata all'arte militare*, Roma.

Cerando, G. 2004. Un secolo e un lustro di fotografia aerea archeologica in Italia (1899-2004), *Archeologia Aerea,* I: 47-68.

Chiusano A., Saporiti M. 1998. *Palloni, dirigibili ed aerei del Regio Esercito 1884-1923*, Roma.

Della Volpe, N. 1980. *Fotografie militari*, Roma.

Iacopi I. 2003. Giacomo Boni, in Capodiferro A., Fortini P. 2003. *Gli scavi di Giacomo Boni al Foro Romano. Documenti dall'Achivio Disegni della Soprintendenza Archeologica di Roma*, Roma, 9-29.

L'Illustrazione Italiana 1900. Le fotografie del Foro Romano, *L'Illustrazione Italiana*, XXVII, 49: 395.

L'Illustrazione Italiana 1907. Giacomo Boni e i suoi scavi nel Foro Romano, *L'Illustrazione Italiana*, XXXIV, 7: 158-162.

Lodi, A. 1976, *Storia delle origini dell'aeronautica militare 1884-1915*, I, Roma.

Lodi, A. 1981. *Il volo a Roma dalle origini ai primi anni del novecento*, Roma.

Pesce, G. 1994. *Maurizio Mario Moris: padre dell'aeronautica italiana*, Gaeta.

Piccarreta, F. 2003. Istituzioni e storia, in Guaitoli M. (ed.*), Lo sguardo di Icaro: le collezioni dall'Aerofototeca Nazionale per la conoscenza del territorio* (catalogo della mostra), Roma.

Piccarreta, F., Ceraudo G. 2000. *Manuale di aerofotografia archeologica. Metodologia, tecniche e applicazioni*, Bari.

Ranza, A. 1903. *Fotografia. Particolari delle esperienze fototopografiche e raccolta di fotografie fatte col pallone ad uso foto-topografico,* Archivio Storico ISCAG.

Ranza, A. 1907. *Fototopografia e fotogrammetria aerea. Nuovo metodo pel rilevamento topografico di estese zone di terreno*, Roma.

Tardivo, C. 1910. *Communication sur la Phototopographie faite au Congrès International de Photographie de Bruxelles,* Archivio Storico ISCAG.

Tardivo, C. 1911. Manuale di Fotografia-Telefotografia. Topofotografia dal pallone,Torino.

Tardivo, C. 1912. *Congrès International de Photogrammétrie. Communication faite sur les travaux de topophotographie exécutés par la Section de Photographie du "Bataillon des Spécialistes",* Archivio Storico .ISCAG.

Taviani, M. 2003. Rilievi eseguiti dalla Regia Scuola d'Applicazione degli Ingegneri di Roma, in Capodiferro A., Fortini P. 2003. *Gli scavi di Giacomo Boni al Foro Romano. Documenti dall'Achivio Disegni della Soprintendenza Archeologica di Roma*, Roma, 51-75.

Tea, E. 1932. *Giacomo Boni nella vita del suo tempo*, I-II, Milano.

Zicavo, E. 1928, *Notizie storiche sulla specialità aerostieri e fotografi del genio del R. Esercito italiano*, Roma.

Images of Conflict: an archival research of Great War air photos and overview of the main applications

B. Stichelbaut, J. Bourgeois

Department of Archaeology, Ghent University, Ghent, 9000, Belgium, birger.stichelbaut@ugent.be, jean.bourgeois@ugent.be

Keywords: aerial archaeology , historic air photos, Great War, conflict archaeology.

ABSTRACT: During the Great War, air photography soon developed to be a whole new science which was used at large scale by all combating nations. This paper examines the existence and use of collections of air photos which were taken during the Great War. These almost industrial products, gathered over four years time, survived in large quantities and archival collections are spread out all over Europe, the United States and even Australia. For the first time, a large archival research was carried out to identify, locate and describe the major collections of Great War air photos. In order to achieve a full understanding of this archival patchwork of aerial coverage, we created a GIS-layer which comprises the geographic coverage of all major aerial photographic collections, where possible combined with a quantification of these records. This very useful tool allows us to determinate which archives will be of interest for particular areas in Europe. Next to an overview of the archive, the paper will illustrate some of the main applications for archaeology, both traditional as conflict archaeology of the Great War.

1 INTRODUCTION

After the first Battle of the Marne (5-11 September 1914), the character of First World War changed from a war of movement into a stalemate in the trenches. The strength and possibilities of the new air weapon were soon recognised. Soon, pilots and observers became the eyes of the army, a role up until then only filled by the cavalry and espionage. As progress was made on the technical aspect of the aerial photography, so was progress also made in the art of reading air photographs.

From the end of 1915 onwards, along the Western Front, photoreconnaissance units were send out on a regular base for different purposes but mostly to record the outline of the enemy's defences. The majority of aerial photography was aimed at the first lines of defences although a lot of strategic missions were carried out to capture information lying far behind enemy lines. Aerial reconnaissance work on the Western Front was conducted by a variety of nationalities. These almost industrial products, gathered over four years time, survived in large quantities and archival collections are spread out all over Europe, the United States and Australia. Not only the Western front is documented in some archives but also other theatres of war (Eastern Front, Gallipoli, Palestine, etc.).

Understanding of the principal goal of aerial photography, gaining intelligence on the enemy, shows us the necessity of a multi-archival approach. Especially if we want to understand front regions rather than particular sites. Allied air photography was mostly directed to the German lines and *vice versa*.

A GIS plotting of most of the still existing and accessible collections has been carried out, not only to have an idea of the dispersion of these sources through Europe. Where possible we wanted to have idea of blind spots and hot zones**,** enabling a realistic assessment of future research zones.

2 ARCHIVAL RESEARCH

A survey of accessible air photo collections dating from the First World War showed that many of these are hidden and forgotten but certainly not lost. Literally hundreds of thousand pictures have survived. Unaffected by the ravages of time they are now being kept in miscellaneous archives. The large amount of preserved pictures are truly astonishing and allude to the real importance of aerial photography during the Great War.

On German side, the head archive of the Bavarian State preserves a collection of a six digit number of aerial photographic prints (presumably 300.000 air photos) . The distribution of this collection can be observed on figure 1 and is based on a preliminary catalogue available at the archive. On the opposite side, the British collection at the Imperial War Museum (IWM) has approximately 135.000 glass negatives available for study. Smaller, but not less important, collections are to be found at the Belgian Royal Army Museum (48.500), US National archives (16.000) and Australian War Memorial (16.000). Unfortunately a survey of air photo collections in France did not reveal solid aerial coverage. Virtually half a million of Great War air photos are available for many parts of the Western Front.

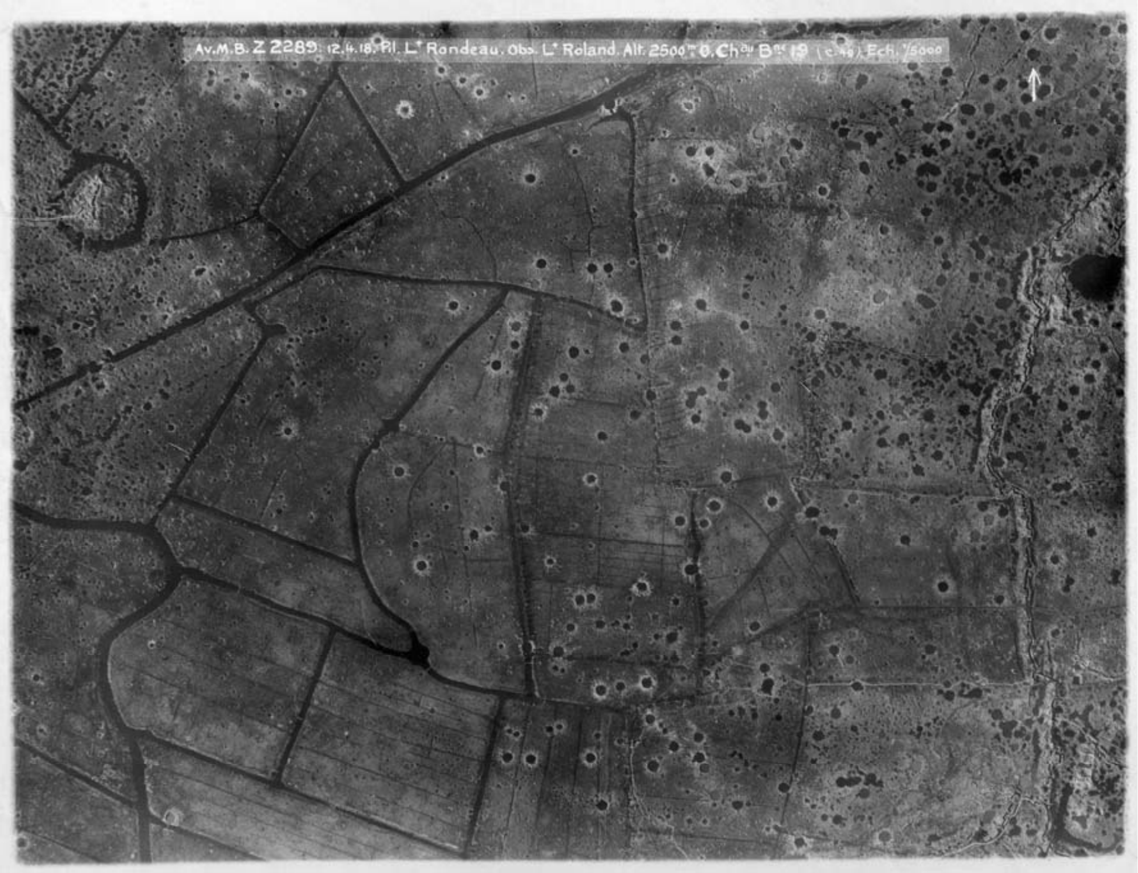

Av.M.B. Z 2289. 12.4.18. Pil. Lt Rondeau. Obs. Lt Roland. Alt. 2500m. 0. Chau Bne 19 (c.49). Ech. 1/5000

Figure 1 Great War air photo (Source Belgian Royal Army Museum)

Naturally, because of their different origins, the characteristics of the collections are very distinct. Most of the collections are composed of aerial photographic prints, while the IWM's Box Collection consists of the original glass plate negatives.

Because of the great importance of these collections, a specific research was set up to gain insights into the quantitative distribution of the Western Front air photos. The innovative aspect in our approach is not the study of historical air photo archives. Collections dating from the Second World War for instance, have been studied into detail (Going, 2002).

For the first time the whole of archives dating from the First World War are being researched. The major innovative and changing aspect of our approach is the analysis of the archives content using a Geographic Information System (GIS). The technique of GIS allows far-reaching possibilities to gain a comprehensive overview of various large collections of air photos. The coverage of several archives and museums is combined and the output data is made as similar as possible. The ultimate product of all our archival research is a GIS layer linking the aerial coverage of different archives combined to a temporal and quantitative aspect where possible. 200.671 APs are located inside a fishnet grid of 5x5 kilometres wide, covering the North Sea up to the end of the Western front near the Swiss-French border.

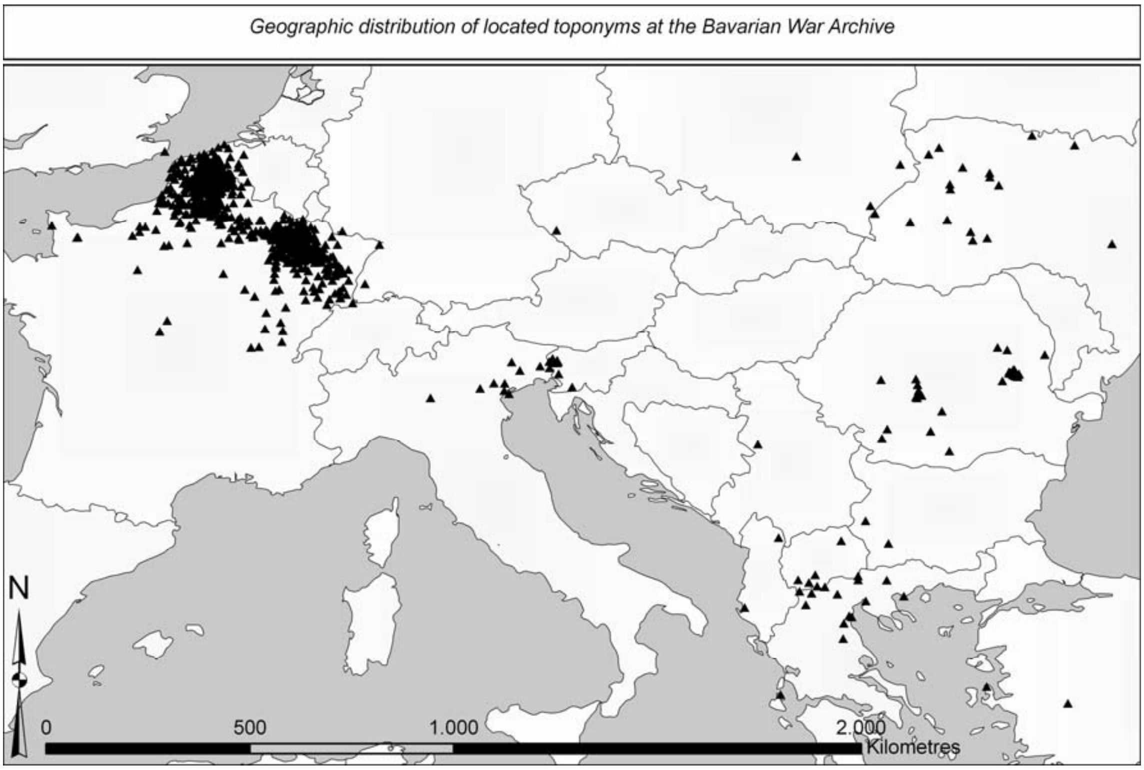

Geographic distribution of located toponyms at the Bavarian War Archive
N
0
500
1.000
2.000
Kilometres

Figure 2 Distribution of the collection of the Bavarian head archive

3 MAIN APPLICATIONS OF THE AIR PHOTOS

3.1 *Aerial prospection*

A first application of the historical air photos is they allow us to detect previously unknown archaeological sites. If we look to some pictures in detail, we can observe hidden in the fields crop- and soilmarks of all kinds of archaeological sites. But because of the high altitude on which the reconnaissance normally took place, somewhere between 2 and 5 km, the recognition of these archaeological remnants remains far from easy.

On the other hand, the continuous artillery shootings destroyed the parceling of the fields. This combined with the deliberate inundation of the some rivers for strategic purposes, provided the ideal circumstances for the detection of watermarks. Literally hundreds of unknown medieval moated sites can be detected; also because many of them were destroyed during the war and are now no longer visible. Medieval and post-medieval city walls and fortifications can be studied on a lot of pictures, more important on places where they are now already destroyed before any archaeological research took place.

Also numerous pictures were taken at the different fronts in the Near East. Their archaeological value for these specific regions was already recognized during and shortly after the war by archaeological pioneers such as Theodor Wiegand and O.G.S. Crawford. They were amongst the first to experiment with archaeological aerial photography, eventually evolving towards the development of aerial archaeology in Europe (Bewley, 2005).

3.2 *Historical geography*

A second important value of these sources is their importance for the study of the landscape at the start of the previous century. More than maps, they can show us how the landscape looked like more than ninety years ago. The air photos have also an aspect of ecological history. For instance in the Yser valley they show valuable field boundaries and little ditches which were use to increase the of grassland profitability. To restore this ecological landscape, historical air photos are used to retrieve the original location of these field systems.

Other interesting study areas might cover the historic extension of the dunes, land-use (Deuel, 1969; Amat, 1988), natural flood areas and afforesting in the front area.

The pre-WW1 landscape is best visible on the earlier pictures, dating before major offensive actions which went together with abundant artillery barrages. These bombardments forced the pre-WW1 aspect gradually to a background role and in some places it just faded away into the lunar landscape for which WW1 became so famous. In less turbulent sectors such as the Belgian-German frontline, this is not so much the case.

3.3 *Conflict archaeology*

When we look at the WW1 APs, we can see promptly the more recent nature of the vast majority of visible features and their connection to the Great War. Pictures were taken along the new boundaries of Imperial Germany reflecting an industrialized war landscape. This military war landscape can be optimally researched by combining early aerial imagery and modern cartographic techniques. Because of the large abundance of these resources we are able to study multiple front sectors time, rather than a site oriented approach. Using GIS, it becomes possible to re-map all the relevant war features to modern maps. These images give us an unparalleled view of the density, distribution and diversity of all kinds of war features, many of which are not described in historical sources (Stichelbaut, 2006).

In a study area of approximately 400 km² between Nieuwpoort and the northern part of the Ypres, more than 28.000 war features were recorded, complete with an indication of their construction date and evolution. The dimensions of the research area and detail of the inventory is unparalleled. Up to know, these historic air photos have been dominantly used for the illustrative value instead as primary sources.

4 CONCLUSION

In this paper we want to stress on both the existence and possibilities of Great War air photos. For many areas these pictures are the first air photos available and often they are covering large surfaces. Approximately half a million of air photos are available for the Western front alone. The application of these sources can run from an aerial prospection of archaeological sites of different periods (up to the conflict archaeology of the Great War) to an ecological history study. In all of cases we have the advantage of the age of these pictures.

5 REFERENCES

Amat, J.-P. 1988. La photographie militaire aérienne, source pour l'étude des paysage ruraux de la Grande Guerre. Vues d'en Haut 14/18, in Humbert J. P., *La photographie aérienne pendant la guerre de 1914/1918*, Paris, Musée de l'Armée, 37-42.

Bewley, R. 2005. Aerial Archaeology. The First Century, in Bourgeois J., Meganck M., *Aerial Photography & Archaeology 2003. A century of information*, Ghent, Academia Press, 15-30.

Deuel, L. 1969. *Flights into Yesterday. The story of Aerial Archaeology*. Suffolk, Penguin Books.

Going, C. 2002. A neglected asset. German aerial photography of the Second World War period, in Bewley R., Raczkowski W., *Aerial Archaeology. Developing Future Practice* (= Nato Science Series I: Vol. 337), Lesno, IOS Press, 23-30.

Stichelbaut, B. 2006. The application of First World War aerial photography to archaeology: the Belgian images, *Antiquity*, 80, 307 : 161-172.

Aerial survey and ancient landscapes in Salento (southern Apulia). Combining advanced technology and traditional methods

M. Sammarco

LabTAF - Department of Cultural Heritage, Salento University, via Dalmazio Birago 64 – 73100 Lecce, Italy. E-mail: labtaf@ateneo.unile.it

Keywords: archaeological air-survey, photo interpretation, ancient landscapes, Salento Peninsula.

ABSTRACT.

Within the framework of the consolidated activity in air-photo interpretation, focused to the reconstruction of ancient landscapes and the creation of thematic cartography of ancient settlements, the Laboratory of Ancient Topography and Photogrammetry (LabTAF) of the Department of Cultural Heritage at the Salento University, has started a long-term programme of archaeological air-survey in Salento, the southernmost part of Apulia region.

The fruitful experience conducted within the UE project «European Landscapes. Past, present and future» carried out thanks to the effort by the English Cultural Heritage, allowed us to test specific procedures for the organization and the management of data-fligths and for archaeological exploration, combining traditional methods of field survey and air-photo analysis.

Aerial surveys were carried out along the coast of Salento Peninsula, documenting well-known settlements, and several new coastal sites visible as crop-marks and damp-marks. The inland territory was systematically explored by field survey along a wide study-area situated between Lecce and his ancient port at San Cataldo. A specific analysis was carried out on the roman pier, producing 3D visualization and DTM, whilst geophysical analyses were carried out in the area of a roman *figlina*.

1. AIR-PHOTO INTERPRETATION AND THEMATIC CARTOGRAPHY

The research activity carried out since more then 15 years by the Laboratory of Ancient Topography and Photogrammetry (LabTAF, directed by Prof. Marcello Guaitoli) of the Department of Cultural Heritage at the Salento University in the field of remote sensing, and based upon analysis of the historical and recent air-photos (Ceraudo, 2007), is addressed toward the preduction of archaeological cartography, supported by consolidated survey techniques (Guaitoli, 1999).

Recently, the technological development has modified both methodologies and tools for a correct knolwedge of the ancient landscapes. The Laboratory has therefore acquired a GIS to store, manage, elaborate and update the informations (Guaitoli, 2001) Data regardings the researches carried out in different sectors of the central-southern Italy are stored in this system.

Further, the Laboratory has a rich air-photo archive, with historical and recent vertical photos, and is equipped to perform the most updated techniques to read, interpret and elaborate air-photos, and to carry out photogrammetry restitutions.

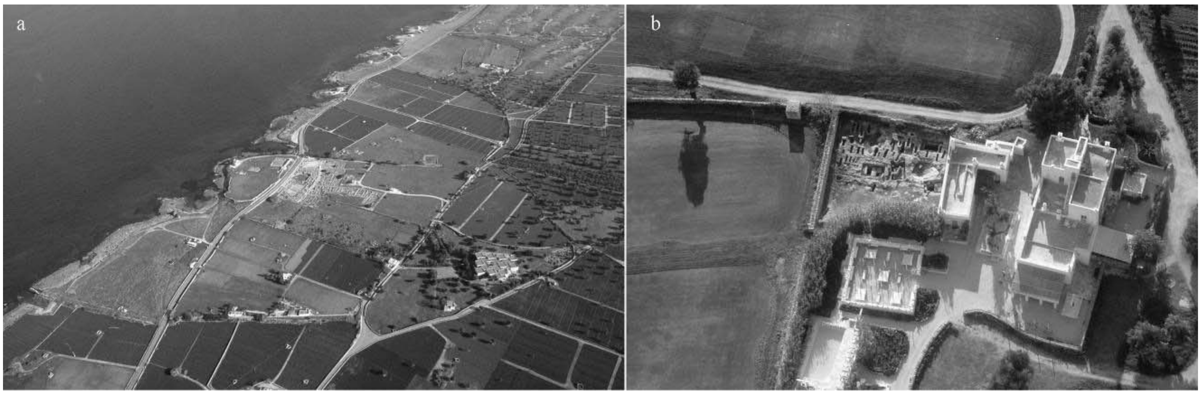


Figure 1 a. Coastal settlement at Egnazia (Fasano). b. Part of the southern necropoli untouched by recent building constructions.

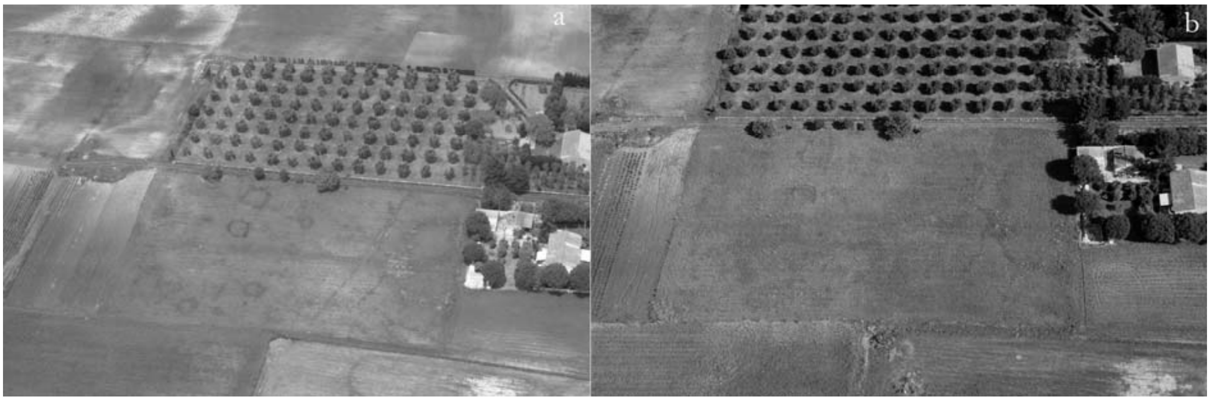


Figure 2 Rectangular cropmarks, probably small squared-ditched enclosures. a: air photo of May, 7th 2006. b: the same area in a photo of June, 9th 2006.

2. ARCHAEOLOGICAL AIR-SURVEY IN SALENTO

The recent law changes regarding air photography (Ceraudo, 2004; *Musson et al.*, 2005) allowed since 2006 to develop a specific long-term archaeological air-survey programme in Salento performed through low elevation flights for shooting oblique images.

The fruitful experience conducted within the UE project «European Landscapes. Past, present and future» carried out thanks to the effort by the English Cultural Heritage, allowed us to test specific procedures for the organization and the management of data-fligths (new archives of oblique photos, GPS track-logs from the flights, GIS data entry) combining traditional methods of field survey and air-photo analysis.

Aerial surveys were carried out along the coast of Salento Peninsula, documenting well-known settlements, as Rocavecchia and Egnazia (figure 1), and several new sites visible as crop-marks and damp-marks (figures 2 – 3a).

Iland, the studied settings include urban settlements and monuments of significant archaeological and architectural interest (figure 4).

In particular, the project explored the archaeology of the relationship between Lecce, a pre-Roman settlement which later on became a Roman colony, and its port at San Cataldo on the Adriatic Sea some 12 kilometres away, which managed its overseas commerce activities in the past. The landscape between the two sites is rapidly changing because of aggressive agricultural development, the urban expansion of Lecce and tourist development along the coast. Thus, the knowledge acquired by the project can be used to assess the past use changes and to establish the correct ways to exploit this sector of the coastline, making sure that the local cultural and archaeological heritage is safeguarded.

During the course of the project 60 hours of flight time covered the area under investigation and other large sections of the Salentine peninsula and the Adriatic coast, collecting more than 300 photographs. Aerial survey flights over the study area and its surroundings were carried out with ideal soil and sea conditions and visibility.

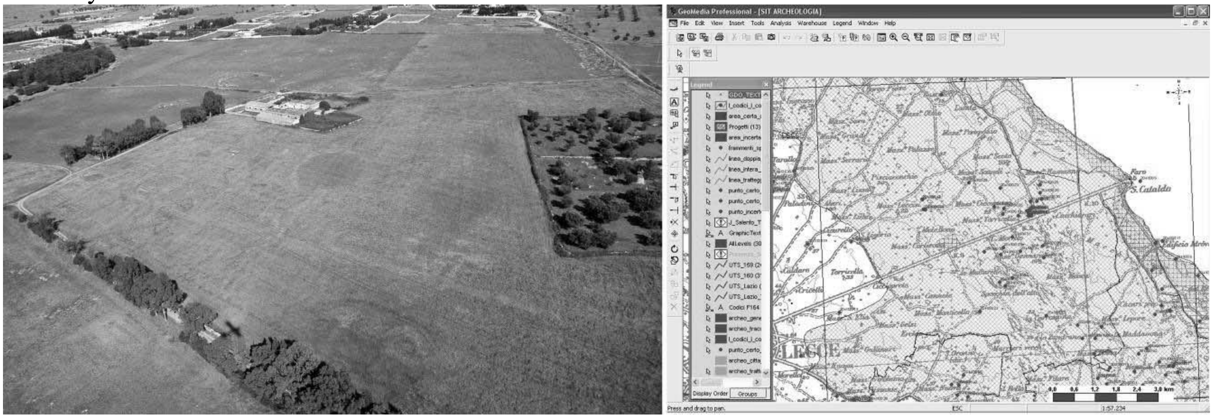

GeoMedia Professional - [SIT ARCHEOLOGIA]
File Edit View Insert Tools Analysis Warehouse Legend Window Help
Legend
Display Order Groups
S. Cataldo
LECCE
Press and drag to pan.

Figure 3 Left: circular cropmark of a likely neolitic settlement. Right: GIS screen with the study-area between Lecce and San Cataldo.

During the field surveys traditional field-walking and survey methods were combined with digital topographic methods. Every single topographical unit was surveyed and mapped using a GPS and all of the resulting information have been organised into a specific database, with the aim of exploiting the spatial analysis capabilities of GIS. The GIS was utilised not just as an instrument for containing and organising data or producing high quality maps, but also as a system for allowing material acquired on site to interact with information regarding the landscape, geology, soils, elevation data and land use (figure 3, right). In conclusion, field survey brought to light 25 new sites dating mainly to Late Antiquity and the early Middle Ages, lying in the territory between Lecce and San Cataldo.

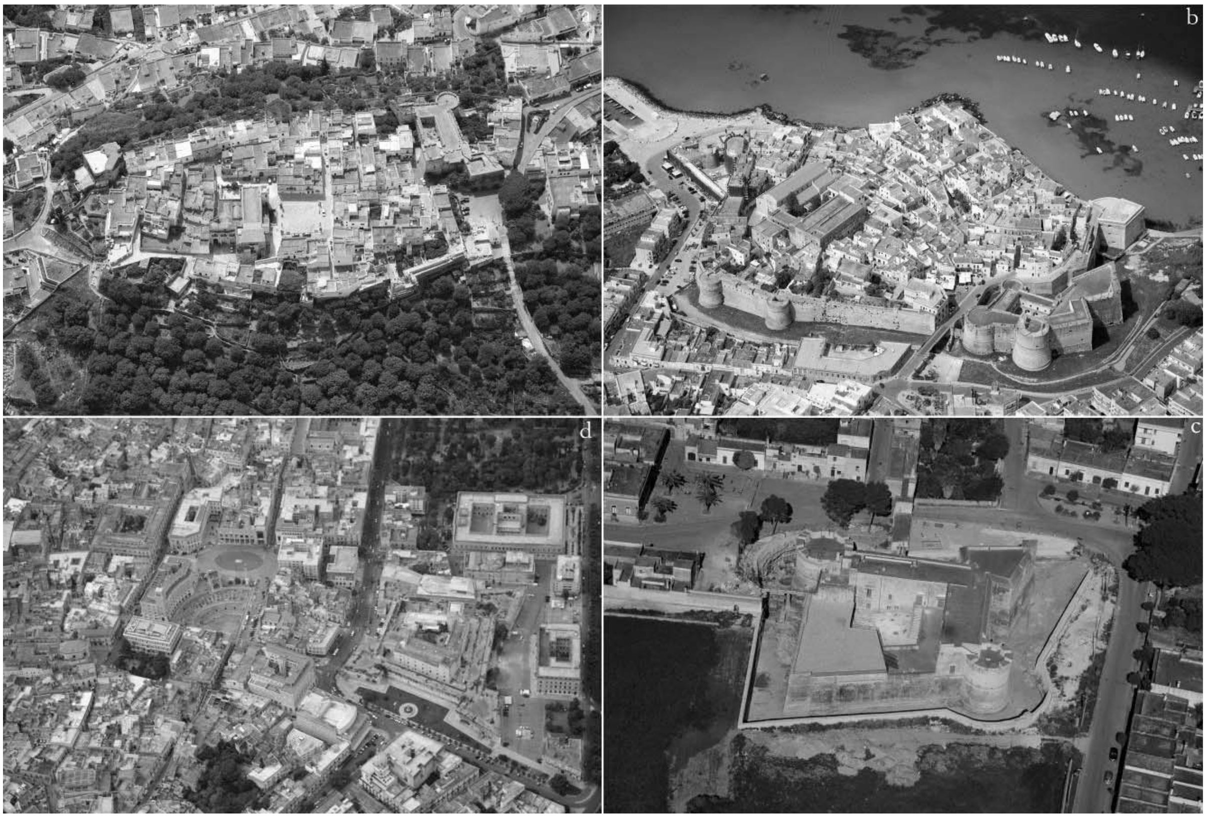


Figure 4 a. The historical center of Castro (Le) and the 16th century castle. b. The fortified settlement at Otranto (Le). c. Lecce, historical centre: Piazza Sant'Oronzo , showing the remains of the roman anphiteatre and castle of Carlo V. d. The Acaya castle (Vernole).

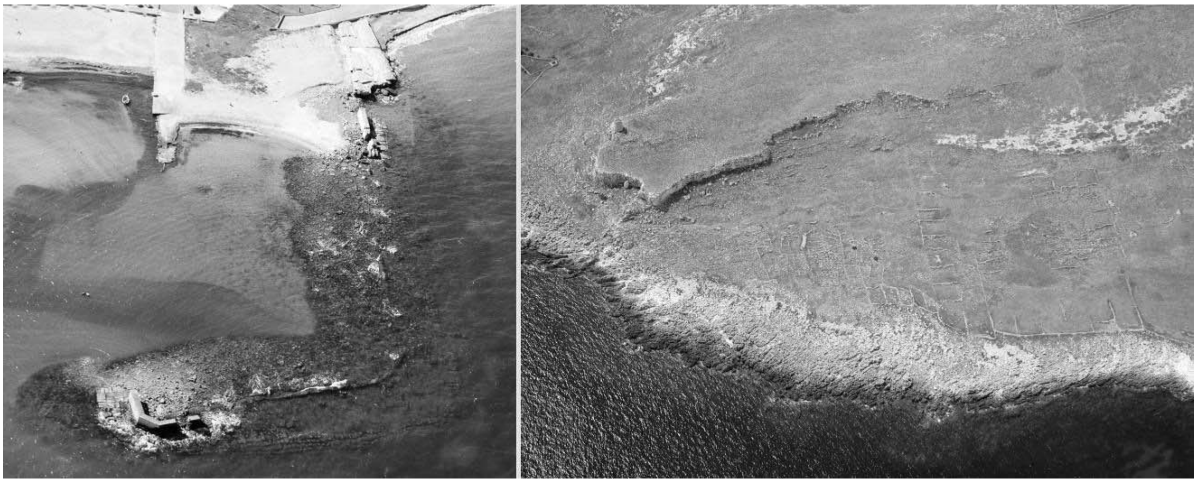


Figure 5 Left : the remains of the Roman pier at San Cataldo. The oblique air-photo shows how the ancient structure was re-used when the modern L-shaped pier was built in 1901. Right: coastline south from Otranto; the tipical dry-stone walls, used to delimitate the fields, are well visible.

3. GEOPHYSICAL ANALYSIS AND 3D VISUALIZATION

In the area between the ancient city and the sea, near Masseria Ramanno, already known thanks to the discovery of a Roman Republican kiln site in 1997 (Valchera & Zampolini, 1997) humidity and cropmarks in the oblique and vertical aerial images allowed a better definition of the settlement that was used to produce amphorae for overseas transportation. The University of Siena research group further surveyed the area, using magnetometer prospection over an area of approximately one hectare. The evidence found made it possible to identify, with high degree of precision, at least two kilns and 3 wall structures.

Along the Adriatic coast, the ancient port at San Cataldo is well known for the ruins of a Roman pier. Here, oblique-photo analysis and interpretation revealed a large L-shaped structure under water, built in 1901 by using large stone blocks taken from the Roman pier (figure 5a). The huge quantity of historical and cartographic documentation found in the archives, together with the data from aerial surveys and the field work carried out directly on the structure, made it possible to reconstruct the history of the port from ancient times onwards (Sammarco & Marchi, 2008). The work on the Roman pier made it possible to clean the structure, record it in detail and elaborate 3D visualizations.

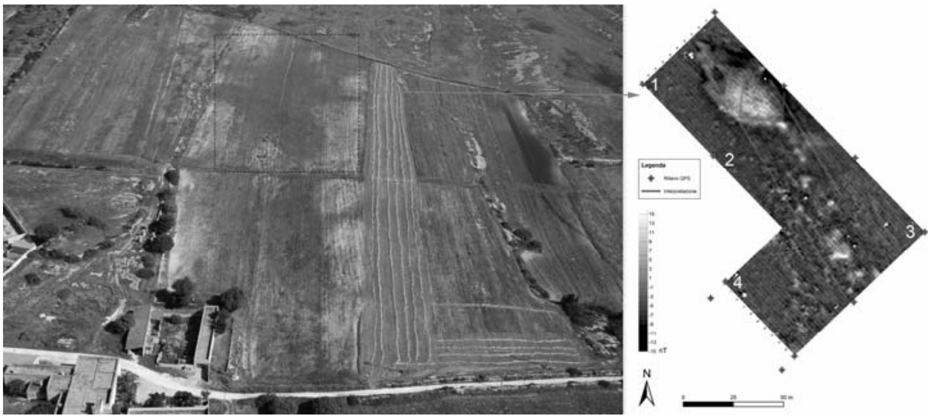


Figure 6 Masseria Ramanno (Lecce); oblique air-photo of the figline area (II sec. B.C.) and graphic restitution of the magnetometer data (Lap&tLab – Siena).

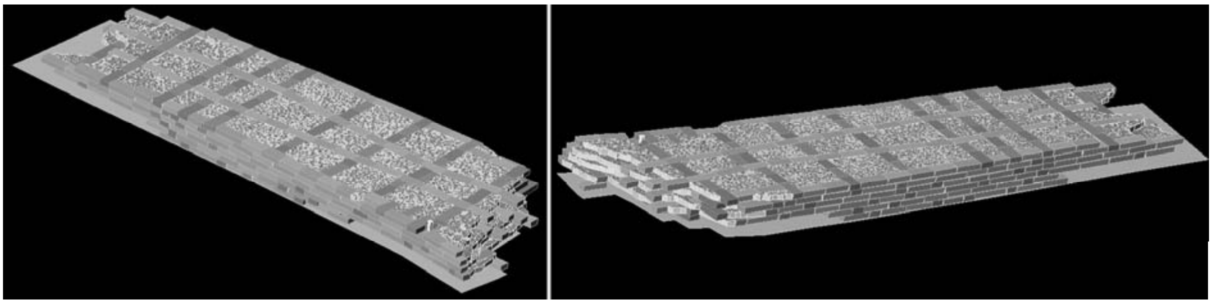


Figure 7 3D Riconstruction of the roman pier in opus caementicium at San Cataldo (Lecce).

4. REFERENCES

Ceraudo, G. 2004. Un secolo e un lustro di fotografia aerea archeologica in Italia. *Archeologia Aerea* I : 47-68, Roma, IPZS.

Ceraudo, G. 2007. *Sulle tracce della Via Traiana. Indagini aerotopografiche da Aecae a Herdonia.* Foggia, Claudio Grenzi Editore.

Guaitoli, M. 1999. Appendice III. Nota sulla metodologia della raccolta, dell'elaborazione e della presentazione dei dati, in Tartara, P., *Torrimpietra (IGM 149 INO)*, *Forma Italiae* 39, Firenze, Leo S. Olschki Editore, 357-365.

Guaitoli, M. 2001. I sistemi informativi territoriali in rapporto al patrimonio archeologico, in *Atti del XL Convegno di Studi sulla Magna Grecia* (Taranto, ottobre 2000), Napoli, 385-402.

Musson, C., Palmer, R., Campana, S. (eds.) 2005. *In volo nel passato. Aerofotografia e cartografia archeologica.* Firenze, All'Insegna del Giglio.

Sammarco, M., Marchi, S. 2008. Il porto antico di San Cataldo (Lecce): indagini tradizionali e nuove metodologie per uno studio topografico. *Archeologia Aerea* III : 165-205, Claudio Grenzi Editore,.

Valchera, A., Zampolini, S. 1997. Documenti per una carta archeologica della Puglia meridionale, in *Beni Archeologici Conoscenza e Tecnologia.* Quaderno 1.2, Martano Editore – Edipuglia, Lecce-Bari, 103-158.

The "Via Traiana Project"

V. Ferrari

LabTAF - Department of Cultural Heritage, Salento University, Via Dalmazio Birago 63 – 73100 Lecce, Italy. E-mail: labtaf@ateneo.unile.it

Keywords: Via Traiana, archaeological aero-topography, vertical and oblique photos

ABSTRACT

The "Via Traiana Project" is part of the activities of the Laboratory of Ancient Topography and Photogrammetry (LabTAF) of the University of the Salento - Lecce (Italy).

The topographical approach for the reconstruction of the route of the Via Traiana, allows us to face it an organic, systematic and analytic way. The researches, for these reason, have been carried out along all the ancient road, realized under the Emperor Traiano in the 109 AD in order to connect in an easier way - even if longer - Benevento with Brindisi, in alternative to the inner and winding route of the Via Appia.

Beyond the activity on the ground, great space has been dedicated to the specialist analysis of vertical and oblique air photographs, fundamental instrument for the acquaintance and the documentation in the studies of "archaeological aero-topography".

A special attention has been given on the stretch of the Via Traiana that crosses the Tavoliere, in the northern part of Apulia, near Foggia, between the ancient cities of Aecae (Troia) and Herdonia.

There is a great deal of aerial photo documentation (vertical and oblique photos) of the *Aecae-Herdonia* section of the Via Traiana.

The quantity and quality (the ease with which you can recognize traces of the road) of this documentation renders it fundamental in providing a more accurate reconstruction of the route it took.

The Roman road is easily recognizable as parts of it have survived and been incorporated into modern roads and other parts are visible as traces on aerial photos – both old and recent – and in numerous oblique photos taken during recent aerial surveys by LabTAF.

All of this material, which is full of direct and indirect traces relating to the ancient road, means that it is possible to document and follow the whole route from Aecae to Herdonia.

The «Via Traiana Project» (Ceraudo, 2008) fits in the activities of research carried out by the Laboratory of Ancient Topography and Photogrammetry in the National Heritage Department of the Salento University in Lecce. The project involves the territory crossed by the main Roman thoroughfare and is pursued according to the experience estate of the "ancient topography", methodologically and technically updated.

Following the traditional sources for this type of investigation, the innovative methodological approach to the archaeological problematic of the territory is qualified by the attention to some of the new technologies and especially to the remote sensing systems. In this last years the evolution of the discipline has considerably progressed, mainly for the availability of new instruments arising from technological progress and from the tight integration with other disciplines, both in the humanistic field and in natural sciences.

With the intention to renew this line of research, but without losing sight of the fundamental targets of knowledge to be achieved through the topographic field investigation, we have to corroborate that this type of activity is necessarily supported by the consolidated techniques of direct field reconnaissance. In fact, one of the elements that most qualifies archaeological topography is the survey, integral and systematic.

New methods of recording were applied to the results of the survey, also cartographic, concerning the presence and the distribution of archaeological testimonies, taking into consideration both the absences and geo-environmental factors that may have influenced, conditioned, limited or avoid the direct field reading on the ground, describing the degree of legibility in the "visibility" charts of the reconnaissance land.

The complexity of the adopted strategy and the enormous quantity of acquired data have made indispensable the realization of a GIS system for the archiving, managing and processing of the information gathered so far, logical development of the field researches, of the finalized cartography and of the photointerpretation. The Territorial Information System of LabTAF was realized by gathering the experiences and the technologies developed in more than a decade of applications, through successive thinning in a number of sample areas representative of the national situation.

Within the "Via Traiana Project," then, the researches have been conducted throughout the whole layout route of the ancient road network, built by emperor Traiano in 109 AD, to connect with an easier path -

although longer - Benevento with Brindisi, as an alternative to the inmost and tortuous path of Via Appia (figure 1).

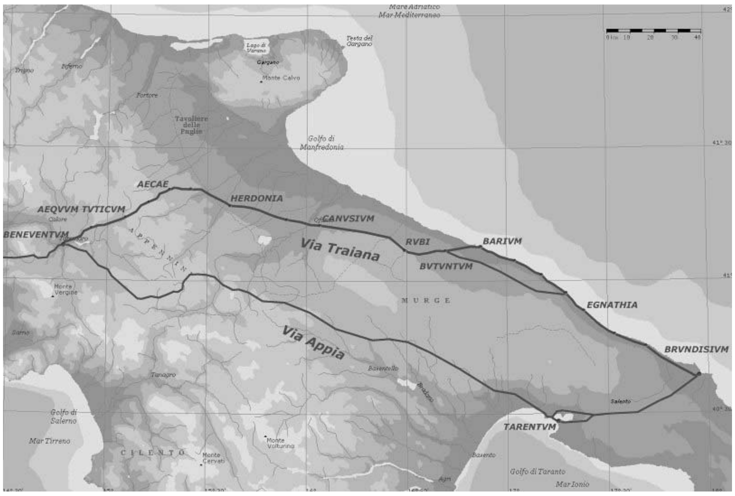


Figure 1 The routes of the Via Traiana and the Via Appia from Beneventum to Brundisium

It was certainly an enterprise concluded in several years of work, even adjusting existing roads: we can deduct the year of starting works - 109 AD - from Traiano’s XIII *tribunicia potestas*, position indicated on the milestones inscriptions; instead the dedication of the triumph arch offered to the emperor by the Senate and the Roman People in Benevento placed at the entrance of the street, is dated 114 AD. On some coins issued from 112 AD is represented, on the reverse, the personification of the via Traiana: this is depicted as a laid female figure resting on a rocky horn that could symbolize the Appennino mountains crossed by the road, who with the right hand supports a wheel leant on the legs (clear reference to travel by land), while with the left holds a gnarled twig (probably olive, typical culture of Puglia region, point of arrival of the street); with the legend *S(enatus) P(opulus)q(ue) R(omanorum) optimo principi*. Via Traiana (figure 2).

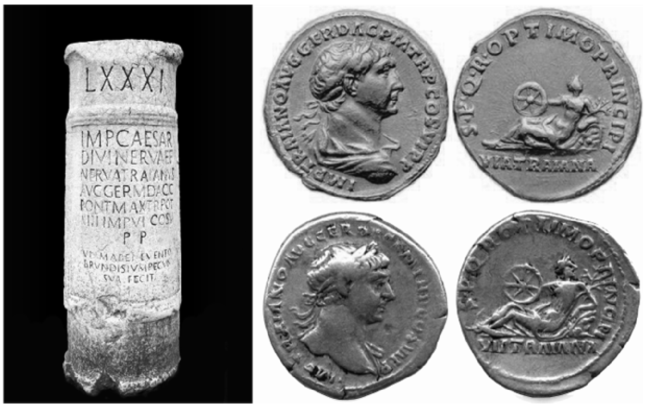


Figure 2. One of the milestone of the Via Traiana, Cerignola (Fg) and the coins with the personification of the Via.

The aerial topographic study has touched all the major centres and stations interested by the passage of the road. After Beneventum, leaving from the triumphal Traiano arch, we find *Forum Novum*, then *Aequum Tuticum* in Sant'Eleuterio, city in Ariano Irpino area, then *Mutatio Aquilonis* to be identified with Masseria San Vito, near the source of Aquilo river, the present Celone, station that marked the finis Apuliae et Campaniae and that constituted the station where the road reached the higher point in altitude, nearly 1000 metres above sea-level datum. Leaving Masseria San Vito, the Traiana way descended toward the Buccolo di Troia, pointing towards *Aecae* (another important road junction), the modern Troia. From Aecae, with long straight roads in an area almost completely flat, the route touched first Herdonia (Ordona), then, after having crossed with a bridge (rebuilt in the Middle Ages and still preserved) Ofanto river - ancient *Aufidus* – turned up to *Canusium* (Canosa); then to *Rubi* (Ruvo di Puglia), to *Butuntum* (Bitonto) and to *Barium* (Bari). Here the road achieved the Adriatic coast and flanked it meeting some coast stations before arriving to *Egnathia* (Egnazia).

The via Traiana ended his race in *Brundisium*, the most important Italian port for the East, *caput viae* opposed to *Beneventum* with a total distance covered of 206 Roman miles, equal to a shortly less than 305 kilometres.

The feat, obviously of considerable financial commitment, was realized also with an impressive technical effort, both in the construction of the road-bad and his paving in correspondence of the passages within or near the cities, and in the realization of the necessary infrastructures. Several bridges, among the most impressive made in Italy in antiquity, were built to overcome the main rivers (figure 3).

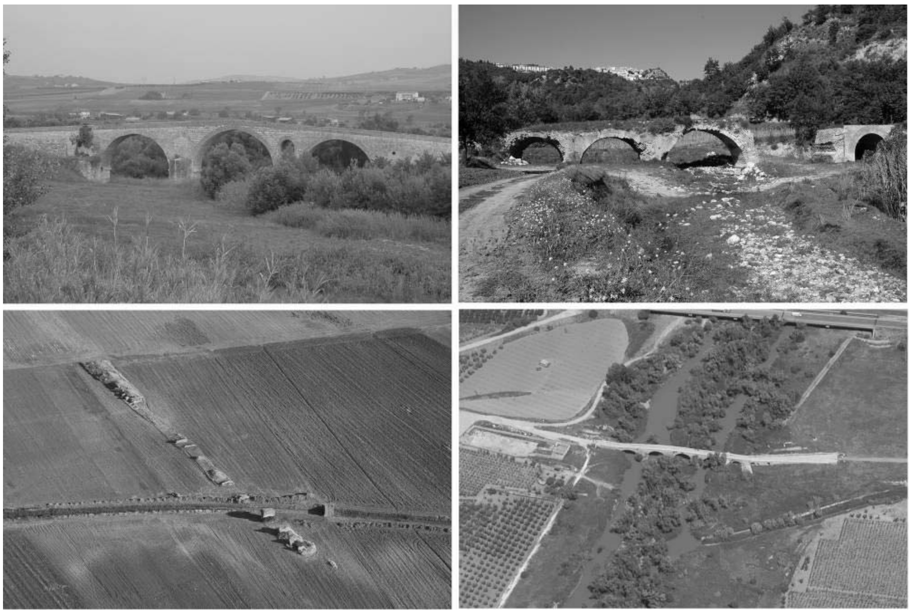


Figure 3. From left up Ponte Valentino on the river Calore , Ponte delle Chianche on the stream , Ponte Rotto on the Carapelle and the bridge on the river Ofanto.

In addition to the activity on the field, great space has been dedicated - as usual - to the specialized analysis of the vertical aerial photography, that is a fundamental instrument for the knowledge and the documentation in the studies of "archaeological topography", which represents, with its applications, one of the sources who offered the most useful results for the studies of this sector.

The research activity of the Lecce's laboratory, linked to the aero relieved images, was not confined only to find vertical aerial photographs. More recently in Italy the abrogation of the "Regio Decreto", dated 1939, concerning the aerial shootings, which took place in December 2000, is to be considered among the most significant changes in our specific area, and has finally opened, also in our country, the borders of aerial reconnaissance flights at low altitude and the shooting of oblique images.

Therefore, it was started a specific program of aerial reconnaissance of the area, with photographic surveying at low altitude photography and with aerial oblique shootings along the entire thoroughfare (figure 5).

For the via Traiana the presence of literary and epigraphic sources, of the ancient itineraries, of several milestones, of toponyms, of medieval sources, of the historical cartography and - as already said - of aerial images of different types, in close liaison with the archaeological research conducted on the ground, have made possible a detailed reconstruction of the layout, allowing the comparison and the integration of the data with what has already been reported by influential scholars on the basis of the itinerary sources in our possession: the researches undertaken by Ashby & Gardner (1916) at the beginning of the last century and by Alvisi (1970), especially for the segment-crossing of the Tavoliere Pugliese.

In addition to this type of integrated research - extensively tested in numerous detailed the analytical charts, now fully three-dimensional, not only in the substance but also in the shape (through processing of specific software), allow to carry out with extreme precision complicated measurements on digital models of the ground, in which are taken into account not projected distances on a plan, but in their real altimetrical development, calculating the measure on the climbs that we can meet along the path of a road axis, safety or rebuilt, with its variants.

This type of procedure, replicable in those contexts where the modern morphology has not been completely modified in relation to the ancient, will be applied to reconstruct the entire path of the via Traiana, in particular it has already been tested in the stretch *Aecae-Herdonia*. The portion of the land affected by the passage of the ancient road, including possible variants, has been shaped in 3D, putting above the line of the road, at that point measurable in his real development and in his real plani-altimetrical extension (figure 4).

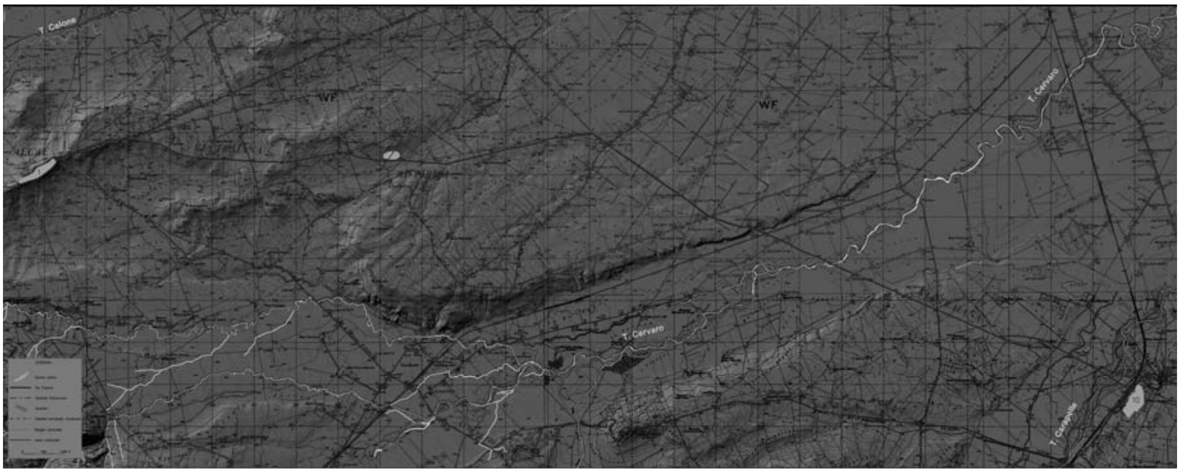


Figure 4. Reconstruction of the stretch of the via Traiana between Aecae and Herdonia on a 3d model.

Of course, as usual in a territorial "topographic investigation", even if aimed at the rebuilding of an ancient road axis, the editing of the archaeological chart has given the right weight and the appropriate space for all the archaeological evidences checked on the ground and on the analyzed aerial photographs: starting - in chronological order - from Neolithic villages, moving to the settlements of *Daunian* age, up to the considerable remains of the Roman agricultural division with sensational traces of farms and ancient cultivation and pre-Roman, Roman and successive viability.

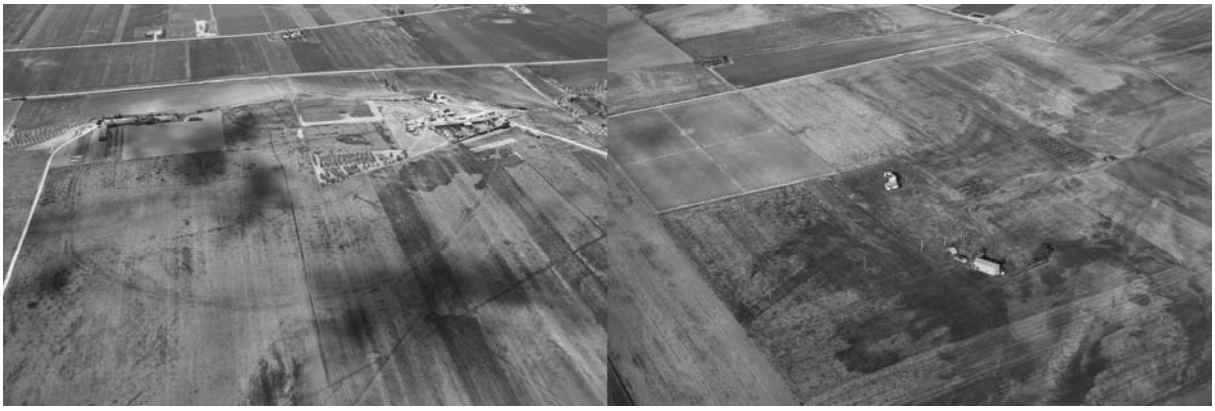


Figure 5. Left: marks of the Via Traiana, a settlement of daunian age and of the roman centuriation near Masseria Ponte Albanito (Fg); right: marks of the Via Traiana and of a Neolithic village near Posta Ricci (Fg).

REFERENCES

Ashby, Th., Gardner, R. 1916. The Via Traiana, *Papers of the British School at Rome*, VIII, 104-171.

Alvisi, G. 1970. *La viabilità romana della Daunia*, Bari.

Ceraudo, G. 2008. *Sulle tracce della Via Traiana. Indagini aerotopografiche da Aecae a Herdonia*, Foggia, Grenzi Editore.

Lilybaeum reconstruction by remotely data

P. Merola, D. Guglietta, S. Sampietri, A. Allegroni, D. Guglietta, S. Sampietri, A. Allegrini

CNR Atmospheric Pollution Institute – V. Salaria km. 29.300, 00016 Monterotondo St.(Rome-Italy)
E-mail: merola@iia.cnr.it

Keywords: Lilybaeum, remote sensing, archaeology, MIVIS airborne hyperspectral sensors, satellite images

ABSTRACT: The identification of buried archaeological structures by remote sensing technologies (aerial photography or satellite and airborne images) is based on the principle that any buried ruins, either of human or natural origin, affects over time, soil surface characteristics create anomalies.

These anomalies are due to different factors, such as soil physical and chemical features, and vegetation cover status. The above factors are strictly connected and are responsible of surface spectral responses.

The study of these anomalies on MIVIS hyperspectral data is the main goal of a research project that the CNR-IIA has carried on since 1994 over some archaeological sites: Selinunte (Trapani), Arpi (Foggia), *Sipontum* (Foggia), Villa Adriana (Tivoli-Roma) and *Lilybaeum* (Marsala).

The MIVIS spectrometer is a passive remote sensing instrument which collect the earth surface radiation from an airborne platform.

MIVIS remote sensing permits to analyse simultaneously a wide range of different wavelengths: these researches have shown that the use of the Visible and Infrared channels of the MIVIS sensor is particularly well useful for the study of cover vegetation and the soil moisture.

In this paper we present the results to reconstructed by remote sensing data (MIVIS data and orthophoto) the ancient urban street network of *Lilybaeum* city.

The digital products derived from different processing techniques, have been interpreted from archaeological and topographic points of view. The results have been compared to earlier archaeological findings. An archaeological trace is the effect on an image of the interaction of different elements which encompass or hide the archaeological object; these elements, of chemical-physical, biological and morphological nature, are humidity, *humus*, vegetation and relief.

Marsala is one of the main urban centres of Sicily, it lies on the Western coastline of the island at about 30 km to the South of Trapani. Founded by the Phoenicians under the name of *Lilybaeum*, it lived intensely during the Punic, Roman, Arab and Norman dominations, as a token of which it still keeps important remnants. The archaeological area, now an Archaeological Park, was variously investigated by means of excavation tests and airphoto-topographic studies.

Lilybaeum's topography has not yet been studied in depth. Schmiedt, by studying some air photos, proposed a reconstruction of the urban street network. This one was constituted by a regular grid of *cardines* and *decumani,* which, crossing at right angle, formed *insulae* 3 x 1 *actus* (35.52 m. x 106.56 m) size.

The urban scheme can be dated to 2nd century BC, following a more ancient plan. Both *decumanus maximu,* coinciding with the main NW-SE trending axis of the promontory, and the orthogonal *cardo maximus* follow the track of 2 actual main urban streets: they are considered as reference elements in the description of the geographical distribution of detected lineaments.

1 PROBLEMS AND METHODOLOGICAL FRAMEWORK

The remote sensing in the archaeological field can be defined as the whole methodologies of acquisition, processing and interpretation of digital images related, to the identification and spatial definition of archaeological sites at intra-situ and inter-situ level in order to plan research activities or landscape planning actions.

To investigate the anomalies (Piccarreta & Ceraudo, 2000) we used the MIVIS (Multispectral Infrared and Visible Imaging Spectrometer) airborne hyperspectral sensors. MIVIS is a modular instrument composed of 4 spectrometers, which simultaneously collect radiation coming from the Earth's surface in the Visible (0.43 - 0.83 μm), the InfraRed (1.15 - 12.7 μm) region (Bianchi *et al.*, 1996).

2 LILYBEAUM

Lilybaeum, the ancient town of Marsala is situated along the island's western coastline, at about 30 km to south of Trapani (figure 1). Now the Punic-Roman city cover roughly 70% of it, while the remaining 30%, free from buildings, constitutes the Archaeological Park. *Lilybaeum* took up a rectangular area on Boeo Cape, a low and rocky promontory sloping gently down towards the sea (Vento, 1999).

The town was founded in 397 BC by the Phoenicians when the population survivor from Mothia, the city destroyed by the Tyrant of Syracuse Dionysius the Elder, chose to live the promontory of Boeo Cape. Under the Carthaginians, the town was a powerful colony which held out against Dionysus' and Pyrrhus' attacks. In 350 BC the new settlement was surrounded by walls and defended by a deep moat, and in the 3rd century BC it assumed the appearance of an Hellenized town. In 241 BC, after the Punic wars, the town was conquered by the Romans (Bovio Marconi, 1961).

Lilybaeum's topography has not yet been studied in depth. In 1960 Schmiedt, by studying some airphotos, proposed a reconstruction of the urban street network (Schmiedt, 1963; Schmiedt, 1970). This one was constituted by a regular grid of *cardines* and *decumani*, which, crossing at right angle, formed *insulae* as large as 3 x 1 *actus* (35.52 m. x 106.56 m).

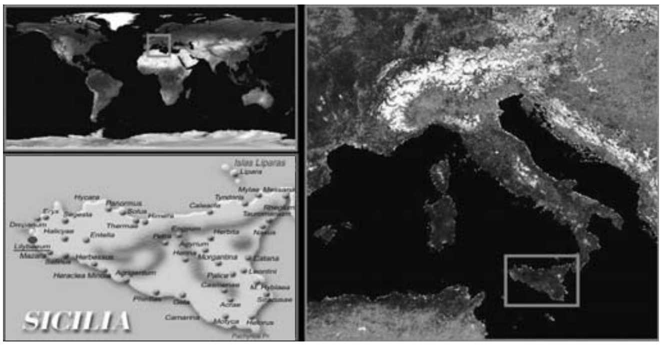


Figure 1. Lilybaeum in world and Italian geographical context.

The urban scheme can be dated to 2nd century BC, following a more ancient plan (De Vido, 1991; Di Stefano, 1993). Both *decumanus maximus* (figure 3, blue line) coinciding with the main NW-SE trending axis of the promontory and the orthogonal *cardo maximus* (figure 3, green line) follow the track of two current main urban streets: they are considered as reference elements in the description of the geographical distribution of detected lineaments.

3 REMOTE SENSING DATA

Remote sensing images, covering the archaeological area of Marsala, were collected during two airborne campaigns: the first, MIVIS data, carried out on July 20th 1994, 10:15 (local time), at an altitude of 2000 m. a.s.l., thus achieving a ground resolution of 4 m/pixels; the second, orthophoto (figure 3a), carried out on October 19th 2006 (ground resolution of 1 m/pixels).

MIVIS data were radiometrically calibrated and geometrically corrected (Bassani *et al.*, 2002); finally the data were normalized according to a known spectral response (concrete square) by the Flat Field Calibration method, in order to obtain an apparent reflectance.

The present study is based on the principle that any buried remnants, either of human or natural origin, affects over time soil surface characteristics creating anomalies, due to different factors, such as:

- soil physical and chemical features
- vegetation cover status.

To highlight the surface anomalies identified in the MIVIS images different hyperspectral data processing procedures were used:

- Principal Components Analysis (PCA - Campana & Pranzini, 2001);
- Computing of Vegetation Index (NDVI - Gong Dao-Yi & Shi Pei-Jun, 2003);
- Supervised classification Spectral Angle Mapper (SAM - Kruse *et al.*, 1993).

The images, derived as output of different methods, were interpreted from archaeological and topographic points of view. The results have been a number of traces drawn and compared with earlier archaeological findings.

4 DATA PROCESSING AND ANALYSIS

4.1 *Principal Components Analysis (PCA)*

The analysis of the PC images (figure 2a) enables to recognize a series of linear anomalies referring to a wide extension of the ancient area. To SW of the *decumanus maximus* several traces related to 5 *decumani* (NW-SE orientation) and 3 *cardines* (NE-SW) were located. To NE of the *decumanus maximus* 5 traces, following a NW-SE orientation (*decumani*), and 3 parallel axes with NE-SW orientation (*cardines*) can be outlined. To the north of the investigated area the ancient moat (darker trace) can be located with particular clearness; before reaching the sea, it turned slightly northwards perhaps following the maximum slope line.

4.2 *Normalized Difference Vegetation Index (NDVI)*

The linear anomalies detected in this site were linked especially to vegetation cover status. By analyzing the NDVI image (figure 2b) many archaeological information has been derived so improving the topographic knowledge of the ancient site of *Lilybaeum*: 7 linear anomalies parallel to the *decumanus maximus* and 4 anomalies, crossing at right angle with the *decumanus maximus*, they can be identified as *cardines*, were distinguished.

In the study area it was possible to recognize to the eastern side of the *decumanus maximus* an anomaly in dark colour and rectangular shaped. This trace can be identified as the remnants of one of the public buildings of the city because of both its remarkable size (it covers the whole *insula* in length) and its locations in the area where there was the acropolis of the Punic and Roman town.

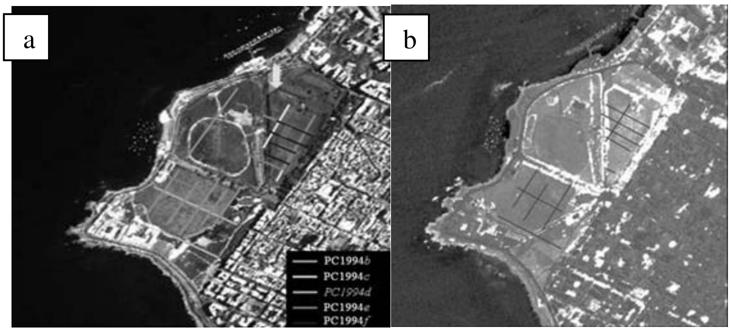


Figure 2: Linear features identified by a) PC's band; b) NDVI index.

4.3 *Spectral Angle Mapper (SAM)*

The analysis of the selected RI*s*, output of SAM classification, have allowed to recognize 17 road axes with NW-SE orientation, which can be identified as *decumani* of the ancient town, and 3 NE-SW oriented parallel lines, namely *cardines*, which perpendicularly cross the *decumani*, so forming some blocks. The *decumani*, located to NE of the *decumanus maximus,* are particularly important as they clearly outline the urban pattern of that sector. The analysis of RI's highlighted, on the plateau to S-W of the archaeological area, some linear anomalies which criss-cross forming a grid of *insulae* with pattern different from that currently documented. This result seems to be interesting since it could prove the superimposition of urban elements testifying a street and block pattern change over the time.

5 INTERPRETATION

The comparison of the results derived from the analysis of the MIVIS images and the ortophoto has permitted to acquire information useful for the recognition of the ancient street network of Lilybaeum located on the basis of anomalies due to the variations of textures, humidity and vegetation of the earth's surface caused by the presence of buried human remnants. A precise archaeological meaning then was ascribed to each anomaly trace taking into account the actual state of art of the archaeological knowledge.

These results are different that the archaeological hypotheses based on traditional investigation methods: taking into account the urban blocks (*insulae*) determined by *decumani* and *cardines* criss-crossing, to the SE of the *decumanus maximus*, they are elongated with a NE-SW trend, while, to the northwest of the same *decumanus*, their longer axis exhibits a NW-SE orientation (figure 3b). It is possible that this urban setting (analogous to that characterizing Selinunte Acropolis) was adopted because of local morphology and problems linked to meteoric water drainage. This archaeological scenario (Di Stefano 1993; Schmiedt, 1963; Vento, 1999) appears to disagree with earlier reconstructions, according to which the whole *Lilybaeum* territory was partitioned into blocks of the same size (3 x 1 *actus*), the same orientation and direction.

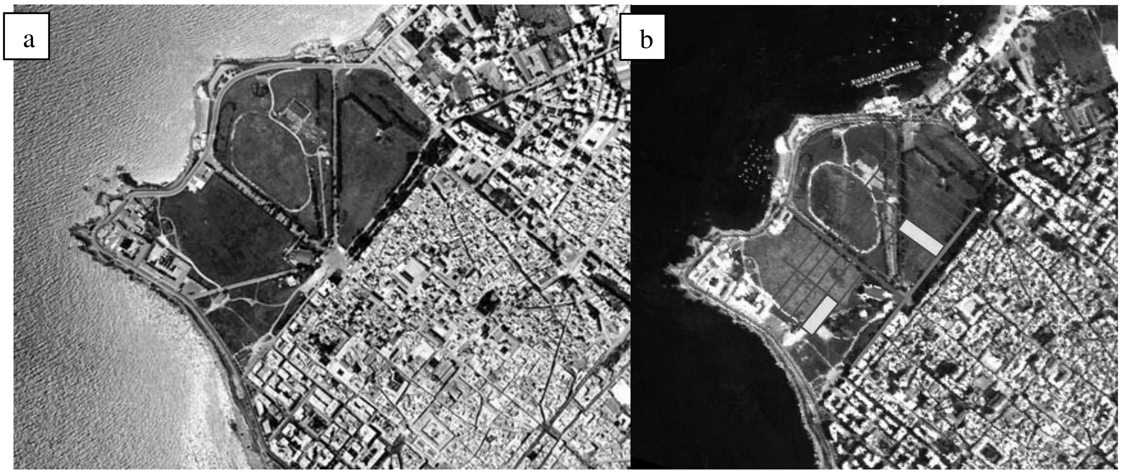


Figure 3: a) orthophotos; b) urban scheme reconstructed by remote sensing data.

6 CONCLUSIONS

The obtained results on the archaeological area of *Lilybaeum* testify how the application of hyperspectral data is innovative, confirming the support that this methodology can offer to the archaeological research and to the traditional surveying methods (aerial photo interpretation, excavation, survey).

7 REFERENCES

Bassani, C., Cavalli, R.M., Palombo, A., Pignatti, S. 2002. La calibrazione dello scanner MIVIS (Multispectral Imaging Visibile and Infrared Spectrometer) nelle campagne di misura realizzate dal CNR nel 2001-2002 in *Atti VI Conferenza Nazionale ASITA "Geomatica per l'ambiente, il territorio e il patrimonio culturale"*, vol. I, p. 337.

Bianchi, R., Cavalli, R.M., Fiumi, L., Marino C.M. and Pignatti S. 1996. Airborne imaging spectrometry: a new approach to environmental problems in *Proceeding of the XVIII ISPRS Congress*, vol. I, pp. 128-132.

Bovio Marconi, J. 1961 Lilibeo in *Enciclopedia dell'Arte Antica*, Italia.

Campana, S. Pranzino, E. 2001. Il telerilevamento in archeologia. Remote Sensing in *Archeology, XI Ciclo di lezioni sulla ricerca applicata in archeologia. Certosa di Pontignano (Siena)*, pp. 34-39.

De Vido, S. 1991. Lilibeo. in *Bibliografia Topografica della Colonizzazione Greca in Italia e nelle isole tirreniche* (BTCGI), Italia.

Di Stefano C.A. 1993. *Lilibeo Punica*, Italia.

Gong Dao-Yi, Shi Pei-Jun 2003. Northern hemispheric NDVI variations associated with large-scale climate indices in spring in *International Journal of Remote Sensing, 24*, pp. 2559-2566.

Kruse, F.A., Lefkof, A.B., Boardman, J.W., Heidebrech, K.B., Shapiro, A.T., Barloon, J.P., Goetz, A.F.H. 1993. The spectral image processing system (SIPS). Interactive visualization and analysis of imaging spectrometer data in *Remote Sensing of Environment, 44*, pp. 145-163.

Piccarreta, F., Cerando, G. 2000. *Manuale di aerofotografia archeologica. Metodologia, tecniche e applicazioni*, Italia.

Schmiedt, G. 1963, Contributo della fotografia aerea alla ricostruzione della topografia antica di Lilibeo in *Κωκαλος IX*, Italia.

Schmiedt, G. 1970. *Atlante aerofotografico delle sedi umane in Italia*, vol. II, Italia.

Vento, M. 1999. *La topografia di Lilybaeum*, Italia.

Airborne hyperspectral remote sensing as a tool for detecting buried archaeological structures: preliminary results for land cover in different contexts.

C. Bassani[1], R. M. Cavalli[1], S. Pascucci[2], S. Pignatti[2]

1 CNR-IIA-LARA, Via Fosso del Cavaliere 100, 00133, Roma, E-mail: cavalli@lara.rm.cnr.it

2 CNR-IMAA, Via Fosso del Cavaliere 100, 00133, Roma, E-mail: pignatti@imaa.cnr.it

Keywords: hyperspectral remote sensing, buried archaeological structures, tonal contrast

ABSTRACT: The capability of airborne hyperspectral remote sensing in the archaeological prospection has been assessed by identifying the anomalies related to sub-superficial archaeological structures. Hyperspectral imagery has been analyzed to recognize the anomalies related to buried man-made structures in different archaeological sites in Italy. The spectral regions, particularly noteworthy from the archaeological detection point of view, have been identified as a function of the land cover characteristics. In particular the tonal contrast observed in the spectral region from the visible to the thermal infrared (0.4-12.8μm) and relative to the archaeological marks has been assessed for the analyzed images. For this study, three main land cover, overlying the buried structures, have been identified for the chosen archaeological sites: (a) photosynthetic (i.e. green low vegetation), (b) non-photosynthetic vegetation (i.e. yellow, dry low vegetation), and (c) dry bare soil. These land cover units have been used in a spectral mixture analysis to retrieve their fractional abundances over the buried structures (i.e. the marks and the relative backgrounds).

Results show that for the land covers characterized by green and dry vegetation, the visible and near infrared regions better enhance the buried man-made structures; while, if dry soils cover the structures, the thermal infrared region is more suitable to detect the buried structures.

This work demonstrates that hyperspectral data with a high spatial and spectral resolution represent an effective and quick tool to detect subsurface structures within different land cover contexts.

1 INTRODUCTION

The application of Remote Sensing data for detecting subsurface structures is becoming a remarkable tool for the archaeological prospection to be combined with the usual geophysical investigations (Rowlands & Sarris, 2007). Different satellite and airborne sensors have been used in a variety of archaeological applications for the identification of spectral signatures within archaeological sites, the mapping of subsurface remains and the management and protection of archaeological sites (Barnes, 2003). Hyperspectral sensors are able to retrieve near-laboratory quality reflectance spectra such that the data associated with each pixel approximate the true spectral signature of a target material (Lucas et al., 2004). As regard the sensors operating on aerial platforms, noteworthy are the AHS (Airborne Hyperspectral Sensor), the AHI (Airborne Hyperspectral Imager), the AVIRIS (Airborne Visible/Infrared Imaging Spectrometer), the CASI (Compact Airborne Spectrographic Imager), the HyMAP and the MIVIS (Multispectral Infrared and Visible Imaging Spectrometer). However, a few hyperspectral airborne data applications in cultural heritage frameworks are cited in the literature (Barnes, 2003). Given the cost implications of acquiring remotely sensed imagery, the arising question is: which is the trade off between high spectral and spatial resolution imagery for archaeological applications? This paper stresses the importance of the spectral information to evaluate the image capability in terms of spectral anomaly detection of subsurface archaeological structures covered by different land cover. The land surface at any given site is composed of a number of man-made and/or natural materials, including the target artefacts and backgrounds composed of soil, rocks (i.e. different minerals) and vegetation. The dominant factors that affect the spectral detectability of an archaeological mark are: (1) the spectral contrast between the target and background materials, (2) the proportion of the target on the surface (relative to the background), (3) the imaging system characteristics being used (bands, instrument noise and pixel size), and (4) the conditions under which the surface is being imaged (i.e. illumination and atmospheric conditions) (Rowlands & Sarris, 2007). However, an archaeological area, depicted by an image pixel, to be positively investigated by remote sensing must have at least a detectable spectral contrast between the buried structures and the background materials against which they are displayed. The detection limit of this spectral contrast is not a constant value, but depends on the instrument characteristics and on the land cover context under which these structures lie. Moreover, the spectral detection of the land cover anomalies related to the subsurface structures requires evaluating the image in terms of spectral mixtures. Within this framework, we present the results of a preliminary investigation of the hyperspectral airborne MIVIS data detectability, on three archaeological sites located in Italy with remains not yet excavated, by analyzing the visible, the near-infrared and the thermal-infrared spectral properties. Three main land covers, lying above the buried structures, have been identified for the chosen archaeological sites: (a) photosynthetic and (b) non-photosynthetic vegetation, (c) dry bare soil. These land cover units have been used in a spectral mixture analysis to retrieve their fractional abundances in the imagery and over the selected archaeological sites.

2 STUDY AREA AND DATA

MIVIS airborne hyperspectral remotely sensed data were used for this research. MIVIS spectrometer is an airborne passive remote sensing scanner (Bianchi *et al.,* 1994). The incoming radiation is recorded by four optical ports, with an IFOV of 2mrad, covering the Visible (0.43- 0.83μm with 20 channels), the Near InfraRed (1.15- 1.55μm with 8 channels), the Short Wave Infrared (1.98-2.45μm with 64 channels) and the Thermal InfraRed (8.18-12.70μm with 10 channels) spectral ranges, for a total of 102 spectral bands (Table 1).

	Spectral Region	**Spectral Resolution (μm)**	**Spectral Range (μm)**	**SNR**	**Spatial Resolution (m)**	**IFOV (deg)**
MIVIS	VNIR (28ch.)	0.02 (VIS) 0.05 (NIR)	0.43-0.83 (VIS) 1.15-1.55 (NIR)	300/1	3	0.115
	SWIR (64ch.)	0.09	1.983-2.478	600/1		
	TIR (10ch.)	0.34-0.54	8.180-12.700	100/1		

Table 1. Characteristics of MIVIS hyperspectral sensor

MIVIS imagery acquired from an altitude of 1500 m a.s.l. (3 m/pixel ground resolution) over Arpi (June 27, 2002), Aquileia (October 13, 1998) and Mothia (May 15, 2002) archaeological areas in Italy were selected for this study (figure 1).

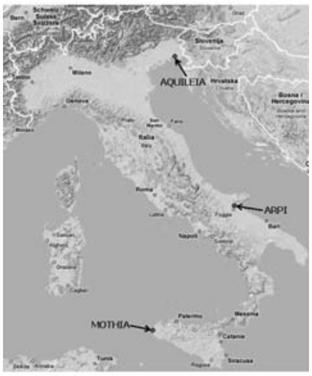


Figure 1. Image showing the location of the Arpi, Aquileia and Mothia archaeological areas (black arrows).

The study areas are characterized by remains (a) not yet excavated, (b) with a sharp geometry, (c) not too deeply buried and (d) on which geophysical surveys and/or archaeological excavation campaigns were performed allowing for an accurate identification of the upper traces relative to the subsurface structures. The Arpi archaeological area encompasses an ancient city of Apulia located 8 km NE of the modern Foggia city in the open countryside and it is considered the metropolis of the ancient Daunia. The Aquileia archaeological area includes one of the largest and wealthiest cities of the Early Roman Empire that was destroyed by Attila in the mid-5th century A.D. The Mothia archaeological area covers an ancient Phoenician colony that was founded at the end of VII century B.C. on the island of San Pantaleo (Sicily).

3 METHODS

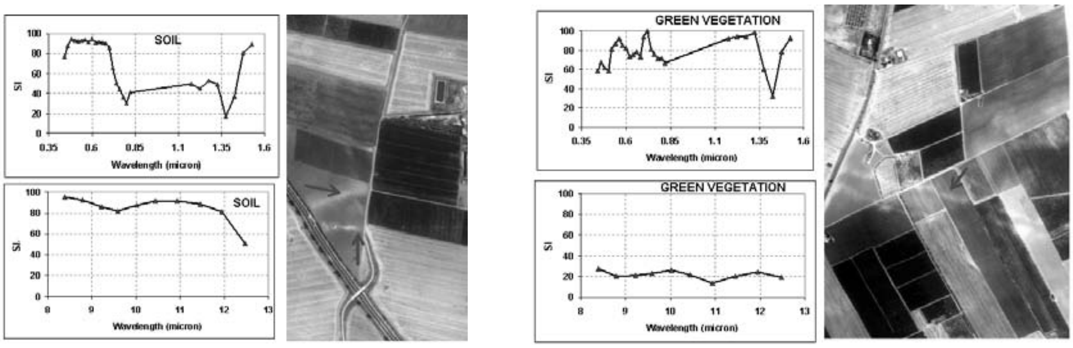
MIVIS imagery collected over the three archaeological areas was first calibrated to the instrument perceived radiances using the internal reference sources and the calibration data gathered from test bench. Second, to work with comparable datasets, they were corrected to reflectance by applying the ATmosphere REMoval Program and further cleaned by residual atmospheric effects by using the EFFORT polishing technique

(ENVI 4.4. software package, ITT). MIVIS Thermal Infra-Red (TIR) data preprocessing, instead, was performed as follows: (i) radiometric calibration of the raw data; (ii) atmospheric correction of the TIR data by using the ISAC (In-Scene Atmospheric Compensation) algorithm (Gillespie *et al.,* 1999); (iii) calibration to apparent emissivity by separating temperature and emissivity according to the emissivity normalization routine described by Gillespie *et al.* (1999) to retrieve apparent emissivities. Last, to rank the capability of detecting an archaeological mark by using hyperspectral imagery when applied to the entire MIVIS scene, the Separation Index (SI) described by Cavalli *et al.* (2007) was used. The SI index describes, for a given image, the tonal differences between the frequency distributions of marks (anomalies) pixels and the pixels selected as background (for the anomalies) and it is defined as a normalized scalar product.

The analysis procedure that was applied to MIVIS imagery was the Linear Spectral Unmixing (Small 2001). MIVIS imagery unmixing was performed using three spectral endmembers: photosynthetic vegetation, non-photosynthetic vegetation, and dry bare soil.

4 RESULTS AND DISCUSSION

The Arpi archaeological area was chosen as main test area and it was analyzed in collaboration with archaeologists (Italian Universities of Rome La Sapienza and Lecce) to identify the anomalies and their archaeological implications in different land cover contexts. First, the SI index was applied to the two examined Arpi sites (Fig. 2) to identify the spectral ranges showing the highest inherent ability of perceiving spectral anomalies, related to subsurface man-made structures, and to rank the archaeological reliance of the sketch map of the marks obtained from the visual interpretation work.

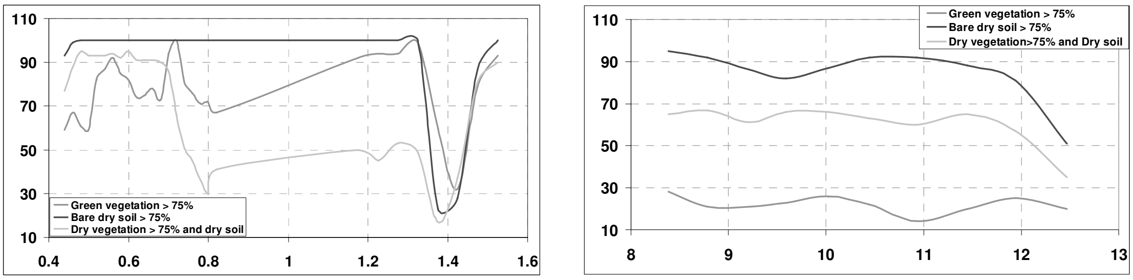


(a) (b)

Figure 2. Arpi test areas; the red arrows point out the structures used to calculate the SI index. The graphs show the SI trend in the different MIVIS spectral regions (VNIR and TIR) for the soil and green vegetation land cover.

These areas were selected because extensive field campaigns were carried out by the archaeologists and also field spectral measurements were acquired. Then, the SI index was calculated for those sectors of the Arpi area that exhibit uniform land cover and lithological outcrops and where a statistically significant number of anomaly pixels were detectable (figure 2). SI values were calculated on the MIVIS single bands to figure out the spectral range bearing the most relevant archaeological information. MIVIS SWIR spectral region was excluded as for the goal of this study the SNR of this spectral range resulted to be too low.

Furthermore, on each test area of the three sites the SI values were analyzed as function of the spectral unmixing results trained with the three, above mentioned, main land cover. This allows assessing the percent occurrence of the land cover for each identified superficial anomaly. Therefore, by analysing the SI behaviour with respect to the MIVIS wavelength bands (figure 3) of the three main land cover (i.e. when fractional abundance is higher than 75%) the most promising spectral region in terms of archaeological detection can be highlighted. As regards the bare soil, both VNIR and TIR regions appear quite effective from the archaeological detection viewpoint. In those sites where green vegetation prevails, the VNIR region is the most suitable for detecting the subsurface structures; in particular at the 560nm and 760nm wavelengths, corresponding to the chlorophyll peak of vegetation and to the water absorption peaks of the leaves. When the subsurface structures are covered by dry vegetation mixed with soil (e.g. wheat stubs), the VIS range up to 700nm shows a similar trend with respect to the soil, while for the bands from 700nm to 1370nm (i.e. the water absorption band), the SI values decrease significantly (i.e. about 40%). Last, as regards the TIR spectral region (figure 3b), its very little relevance (i.e. under 30%) for the detection of structures covered by green vegetation confirms that the presence of vegetation in the context of thermal sensing causes difficulties due almost to the impact of evapotranspiration, which results in a uniform canopy (Ben-Dor *et. al.*, 2001).



(a) **(b)**

Figure 3. Examples of the unmixing results attained for two chosen sites of Arpi by using the three endmembers.

Concluding, hyperspectral remote sensing offers a rich add-on to regional or landscape archaeology studies beyond its utility as simple discovery tools. It is constrained by conditions at the time and place of data acquisition, soil type, ground moisture and ground cover that could potentially lead to poor or no archaeological feature contrasts: it is particularly difficult within urban or forested landscapes. Remotely sensed data costs, frequently viewed as a drawback, must be balanced against the actual larger costs of planning decisions based on little knowledge of what lies beneath the ground, of badly placed excavations, and of failing to locate archaeological features and other culturally sensitive deposits prior to their disturbance. The results of the hyperspectral image processing can be extremely effective when applied to those areas where large cultural heritage assets have to be discovered, surveyed, safeguarded from grave-robbers and protected from environmental to unchecked urban development.

5 REFERENCES

Barnes, I. 2003. Aerial remote-sensing techniques used in the management of archaeological monuments on the British Army's Salisbury Plain training area, Wiltshire, UK. *Archaeological Prospection*, 10: 83-90.

Ben-Dor, E., Kochavi, M., Vinizki, L., Shionim, M., Portugali, J. 2001. Detection of buried ancient walls using airborne thermal video radiometry, *International Journal of Remote Sensing*, *22* (*18*): 3689-3702.

Bianchi, R., Marino, C. M., Pignatti, S. 1994. Airborne hyperspectral remote sensing in Italy, in Proc. EUROPTO series *Recent advances in Remote Sensing and Hyperspectral Remote Sensing*, SPIE, Rome (Italy), 2318, 29-37.

Cavalli, R.M., Colosi, F., Palombo, F., Pignatti, S., Poscolieri, M. 2007. Remote hyperspectral imagery as a support to archaeological prospection, *Journal of Cultural Heritage*, 8: 272-283.

Gillespie, A.R., Rokugawa, S., Hook, S., Matsunaga, T. & Kahle, A.B. 1999. *ASTER Temperature/Emissivity Separation Algorithm Theoretical Basis (Version 2.4).* Algorithm Theoretical Basis Document. Washington, DC.

Goetz, A.F.H., Boardman, J.W. Kindel, B., Heidebrecht, K.B.. 1997. Atmospheric corrections: On deriving surface reflectance from hyperspectral imagers, *Proceedings SPIE Annual Meeting*, 3118, 14-22.

Lucas, R.M., Rowlands, A.P., Niemann, O., Merton, R., 2004. Hyperspectral sensors: past, present and future, In: P.K. Varshney, M.K. Arora (Eds.), *Adv. Image Processing Techniques for R. S. Hyperspectral Data*, 11-40.

Rowlands, A., Sarris, A. 2007. Detection of exposed and subsurface archaeological remains using multi-sensor remote sensing. *Journal of Archaeological Science*, 34: 795-803.

Small, C. 2001. Estimation of urban vegetation abundance by spectral mixture analysis. *International Journal of Remote Sensing*, 22: 1305–1334.

Exploring the Edges of the Unseen: an Attempt to Digital Aerial UV Photography

G. Verhoeven
Ph.D. fellowship of the Research Foundation - Flanders (FWO), Ghent University - Faculty of Arts and Philosophy, Department of Archaeology and Ancient History of Europe, Ghent, 9000, Belgium, Geert.Verhoeven@UGent.be

Keywords: Aerial photography, Aerial archaeology, Ultraviolet photography, UV-A, Near-UltraViolet

Although the sun has its peak emission of ElectroMagnetic (EM) radiation around 480 nm (perceived as visible green), it still produces a great deal of UltraViolet (UV) wavelengths (100 nm – 400 nm). However, the largest portion of this radiant energy is blocked by the ozone layer of the atmosphere, only allowing the Long Wave UV (also called Near-UV or UV-A and comprising the spectral band between 315 nm and 400 nm) to reach the earth's surface. Additionally, sensors acquiring this part of the UV wavelengths must be operated from low altitudes to minimize the effects of strong Rayleigh scattering to which the UV radiation is subjected. Consequently, this waveband of the EM spectrum is rarely employed in remote sensing and its reflected portion is only imaged in very specific applications.

Archaeological aerial UV imaging can thus truly be seen as an almost completely unexplored research field. Although it is far from certain that this technique could enhance, let alone reveal new archaeologically related anomalies, this paper wants to discuss the practicalities of digital UV imaging: from the modification of Digital Still Cameras (DSCs) and the choice of a suited lens over the extremely important UV interference filter to the exposure and focus compensation needed. The use of a previously built, entirely remotely controlled device will shown to be indispensable as the inevitable long shutter speed compels the use of such a very stable, unmanned aerial platform. By presenting the very first archaeologically related aerial UV imagery, the weaknesses and/or advantages over conventional visible imaging might start appearing – notwithstanding the infancy of this approach – while also aiming to discuss the (future) use of this non-visible archaeological imaging.

1 INTRODUCTION

UltraViolet (UV) radiation is a specific portion of the complete ElectroMagnetic (EM) spectrum, comprised between X-rays and visible light, hence spanning a limited range of wavelengths: from 100 nm to 400 nm. Within this particular region, three smaller UV subregions can be defined:

- UV-A: also called Near-UltraViolet or Long Wave UV and ranging from 315 nm till 400 nm;
- UV-B: also denoted Middle/Medium Wave UV and comprised between 280 nm and 315 nm;
- UV-C: divided into Vacuum UV (100 nm – 200 nm) and Short Wave or Far-UV (200 nm – 280 nm) (Ray 1999; Vecchia *et al.*, 2007).

The UV region of interest here is the Near-UltraViolet (NUV) or UV-A subdivision, which is emitted by both the sun and several artificial light sources. Notwithstanding its substantial UV output, only about 5% of the sun's radiant terrestrial energy is UV, as most of the incident UV radiation is blocked by the atmosphere, allowing only this UV-A and some of the long-wave part of UV-B (till about 290 nm) to be transmitted by the ozone layer of the earth's atmosphere (Vecchia *et al.*, 2007). Moreover, the amount of UV radiant energy reaching the earth largely depends on the solar altitude: the elevation angle of the sun above the horizon which varies with the time of day, the period of the year as well as the geographical location. Clouds additionally reduce the UV radiation reaching the earth. Consequently, the amount of terrestrial UV radiation is very low compared to visible light or Near-InfraRed (NIR) radiant energy.

2 APPLICATIONS OF ULTRAVIOLET PHOTOGRAPHY

UV photography exists in two distinct forms: reflected/transmitted or direct UV photography and UV induced fluorescence photography. Aerial photography only applies the first form: monitoring the reflected UV-A portion that is emitted by the sun and partly transmitted by the atmosphere. This is however not as trivial a task as visible light or NIR photography. Not only is the amount of terrestrial NUV rather low compared to the other forms of optical EM wavelengths, but most ground surfaces additionally reflect very little UV-A (normally less than 10%) – sand, water and snow being a few exceptions. Additionally, UV radiation is seriously subjected to strong Rayleigh scattering. Therefore, any sensor acquiring this part of the EM spectrum must be operated from low altitudes to minimize this detrimental effect. Consequently, the NUV waveband is rarely employed in remote sensing, leaving the imaging of its reflected portion only to be used in a few, very specific applications: e.g. detecting and monitoring oil films on water (Gibson 1978; Vizy 1974) or finding white animals on ice and snow (Lavigne, 1976; Lavigne & Oritsland, 1974).

In archaeology, UV photography is rarely used but for the occasional examination of subjects not (or less) responsive to visible or NIR photographic methods. In those cases, UV fluorescence photography (which is based on the emittance of new, visible radiation when an object is illuminated by UV wavelengths) and to a lesser extent direct UV photography might reveal faded inks, altered documents or engravings, can aid in the study of ceramics and help to detect specific pigments as well as traces of restoration on tapestries, paintings and sculptures (Dorell, 1994; Matthews, 1968). From an aerial point of view, direct UV photography has never been used in archaeological research (as far as the author is aware), although Gibson (1978) states it might be useful in revealing soil marks, although no further reference or illustrative material is used to prove this point. Therefore, rather than being an addition to the existing literature or a comprehensive overview of the archaeological potential and all related drawbacks of aerial NUV photography, the material presented here must be seen as an account of the first attempts to visualize archaeologically related anomalies and structures using these shorter-than-visible wavelengths, without having the presumption to be completely conclusive.

3 IMAGE ACQUISITION

To digitally capture NUV, a Digital Single-Lens Reflex (D-SLR) was converted to acquire the full range of wavelengths the digital sensor is inherently sensitive too. When buying an off-the-shelf Digital Still Camera (DSC), the sensor is covered with an UV-IR cutoff filter that only allows visible light to pass, excluding as much UV and NIR radiation as possible. Although these filters come in various qualities (i.e. some DSCs still have a considerable UV and/or NIR response straight out of the box), their aim is equal: excluding these invisible wavelengths from reaching the sensor, because their contribution would be detrimental for image sharpness (the wavelengths have a different focus), exposure accuracy and true colours. By removing this filter, the digital sensor not only becomes highly sensitive to NIR but its responsivity to UV-A radiation increases as well (for an in-depth overview of sensor sensitivity and camera modification, the reader is kindly requested to consult Har et al. 2004 or Verhoeven 2008a).

The DSC used for the UV-A data acquisition is a converted Nikon D80, known to have a very poor UV response as delivered from the factory. By replacing the internal filter package with a specific clear glass that largely transmits NUV (a modification executed by LDP LLC), the D-SLR was made sensitive to about 320 nm (Har *et al.*, 2004). Selecting such an appropriate D-SLR to convert for NUV imaging is as important as the conversion itself, because not all sensors are equally sensitive to UV-A and particular lenses will only fit onto bodies of specific brands. In this case, the choice for this DSC was driven by the fact that the D-SLR is built around a CCD sensor (Charge-Coupled Device), which is know to be more sensitive to UV-A than a CMOS (Complementary Metal Oxide Semiconductor) imaging sensor (Har *et al.*, 2004). Moreover, Nikon is the brand used for other kinds of archaeological invisible imaging (Verhoeven, 2007; Verhoeven, 2008a; Verhoeven & Loenders, 2006; Verhoeven *et al.*, 2008), which makes buying and changing lenses easier as all hardware is centred around only one bayonet system. Finally, most of the UV dedicated lenses currently made all have a Nikon F-mount.

Secondly, the D-SLR was equipped with a Novoflex Noflexar 35 mm f/3.5. Normal photographic lenses are generally impractical for UV imaging, as glass does not transmit a lot of UV and certainly no EM radiation below 350 nm (Hansell & Lunnon 1984; Eastman Kodak Company 1961; Ray 1999, 2002). Moreover, optical cements can have a very high UV absorption and the coatings on the lens elements additionally decrease the UV transmittance (Ray 1999, 2002; Spitzing 1979). Specialized SLR UV lenses with quartz and fluorite elements for sub-350 nm imaging do exist (e.g. UV Micro Nikkor 105 mm f/4.5; Zeiss 60 mm f/4 UV Planar and 50 mm f/2 UV planar; Zeiss UV Sonnar 105 mm f/4.3; Rodenstock UV Rodagon 60 mm f/4; Coastal Optics UV-VIS-IR 60 mm f/4 Apo Macro, Coastal Optics UV 105 mm f/4.5), but these do not come cheap – mostly starting at about € 4000 – nor do they exist in wide-angle variants. However, some older, often exotic lenses still have a useful UV transmission till about 350 nm, largely due to their simple optical design with few lens elements and the absence of multi-coated and cemented elements (Rørslett 2004). Such a lens is the Novoflex Noflexar 35 mm f/3.5, characterized by an excellent UV performance (Rørslett 2008) and having a cut-on transmitted wavelength of about 320 nm (pers. comm. by Dr. Klaus Schmitt from macrolenses.de, who also converted the Novoflex to fit Nikon D-SLRs).

Thirdly, a 2" Baader Planetarium U-Filter (also called “UG11xx” or “Venus Filter”) is mounted onto the lens using some step rings and the Nikon AF-1 Gelatin Filter Holder (a practical method thought of by Dr. Klaus Schmitt). This interference filter – which only transmits from 310 nm till 390 nm – is by far the most important part of the system. By removing the internal UV-IR cutoff filter, the NIR response of the D-SLR increased hugely, making this very dense VIS+NIR block filter of the utmost importance. Without, the final digital frame would still be heavily NIR-contaminated, as is the case when applying most UV band-pass filters: Schott UG1 and UG11, B+W 403, Kodak Wratten 18A, Nikon FF or Hoya U-330, U-340 and U-360 (Rørslett, 2004; Spitzing, 1979). Although these non-interference filters completely block visible light, they substantially leak NIR, spoiling the pure UV-A picture aimed for.

As a converted D-SLR still is moderately sensitive to UV (about the same sensitivity as the analogue silver halide emulsions at 380 nm, although the latter only sense wavelengths till about 360/350 nm - Har *et al.*, 2004) and the amount of reflected UV is generally very low, long shutters speeds will always occur (some 6 up to 15 stops longer exposures when compared to visible photography – Rørslett, 2004). Moreover, the small aperture (e.g. f/8) needed for sufficient image sharpness will even increase the exposure time further. Although this currently makes aerial UV photography practically unusable from a low flying airplane, it can be applied when a suited, stable aerial platform is available. The latter was previously constructed by the author (see Verhoeven & Loenders, 2006; Verhoeven *et al.*, 2008) to allow for digital NIR aerial archaeology by means of a Helikite – a combination of a helium balloon with kite wings. Inaugurated HAP or Helikite Aerial Photography, this form of remote sensing proved essential in the acquisition of the aerial UV imagery (figure 1).

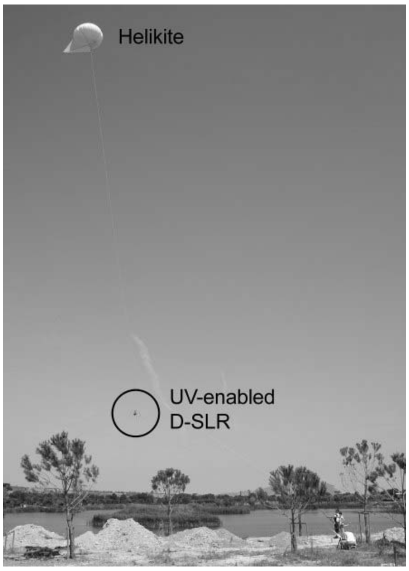


Figure 1. Helikite Aerial Photography to acquire archaeological UV-A imagery (photograph by F. Vermeulen)

4 ARCHAEOLOGICAL RESULTS

With the modified Nikon D80 set to manual exposure (1/50 s till 1/80 s, f/8, ISO 800) and prefocused to just-before-infinity (as for all but a few specialized lenses, focusing the lens closer than for visual photography is needed to counteract the significant shift of focus when shooting NUV), it was possible to acquire some rather sharp aerial imagery over an excavation area (figure 2) and a visibly attested crop mark (figure 3). The results shown are frames that were already subjected to some necessary image processing.

Although UV imagery should by definition not have any colour, the Colour Filter Array (CFA – see Verhoeven, 2008a) and processing software inside a DSC will always create colours from the signals generated by the incoming UV photons. In most DSCs, UV-A imagery will look pinkish or suffer from a reddish cast (Fig. 2B), as this channel has generally the biggest UV-A response. In essence, one can just work only with this Red channel to generate a greyscale result (figure 2C), or alter the White Balance to generate a coloured image that takes all three Red, Green and Blue channels into account. Both approaches largely benefit from a RAW workflow, as does any scientific photography (Verhoeven, 2008b).

In addition to this strong colour cast, UV imagery coming straight off the DSC is also typically low in contrast (figure 2B). Besides extracting only the Red channel, the NUV frame thus benefits from both a histogram stretch as well as some local contrast enhancement. After noise suppression, the end result looks as depicted in figure 2C.

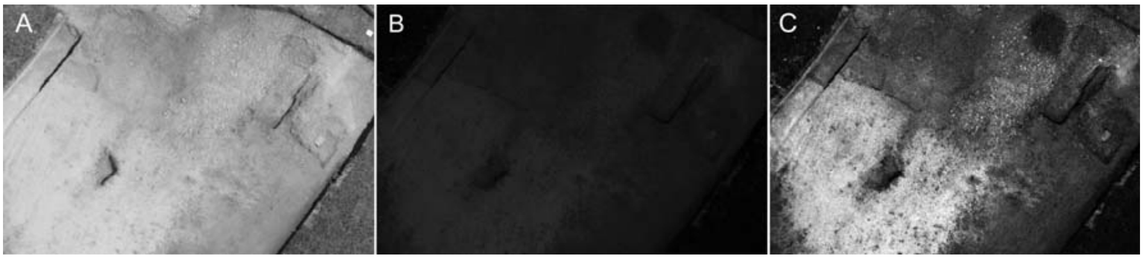


Figure 2. Comparison between a visible frame (A), unprocessed RAW UV image (B) and enhanced UV photograph (C) of an excavation area

When comparing image 2A with 2C, the contrast difference between the white gravel and the surrounding soil matrix is far more pronounced in the NUV compared to the visual record. Moreover, the amount of details visible in the UV frame is at least equal to the conventional photograph, although the latter was taken with a far superior lens and a much higher shutter speed. This fact reveals the higher resolving power of UV photography, to be attributed to the shorter wavelengths used for imaging. Finally, it needs to be mentioned that the large dark blob in the upper right corner of the UV frame has no archaeological meaning, but is nothing more than the shadow cast by the Helikite.

In the second example (figure 3), the cropmark that reveals the presence of the *cardo maximus* of the Roman coastal city of *Potentia* (central Adriatic Italy, Regione Marche) also proved to be visible in the UV records (which are rather limited in ground area covered, due to the focal length of the lens applied in combination with the altitude of the Helikite). Whether this result means all cropmarks can also be spotted in the NUV, is however far from certain. Looking at the visible record, it seems the archaeological feature is mainly visible due to a scarcely vegetated surface, rather than a discoloration of the grass. This observation seems to be confirmed by examining the UV frame, from which it is likely that the lighter trace was yielded by the higher reflective ground visible between the otherwise very dark vegetation. As indicated before, these first examples only want to give the initial impetus to a further examination of NUV aerial archaeology, rather than already judging its potential or uselessness. Moreover, to really research UV reconnaissance in a more systematic way, a shorter focal length lens is elementary – to allow for a larger ground coverage – while a dedicated UV quartz lens could make shorter shutter speeds possible, most likely resulting in a lower percentage of blurred imagery and/or allowing the ISO value to decrease (which is essential to tackle the noise in the darker image areas).

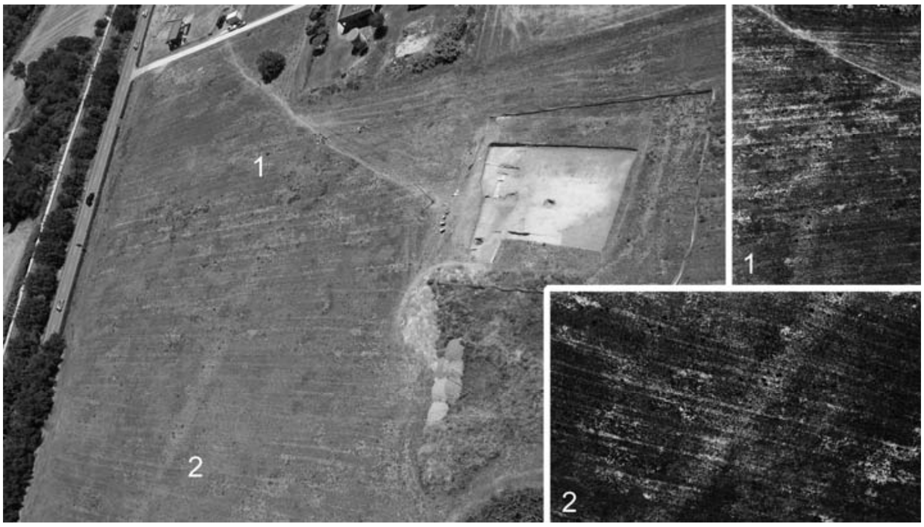


Figure 3. Comparison between a visible record of a cop mark (left) and its rendering by UV-A wavelengths (right)

5 CONCLUSION

By imaging beyond the limits of the Human Visual System (HVS), digital Near-UltraViolet photography extends the conventional vision offered by aerial archaeology. Looking at the very first digital NUV aerial frames acquired, this new way of imaging already seems promising to enhance differences in soils. The extent to which this observation is applicable (e.g. kind of soil) and its complete understanding (e.g. contrast due to a particular moisture content or soil texture or ...) still remain open for further exploration, just as the question whether or not this technique can reveal anomalies other spectral bands are unable to display. However, as both the specific photographic hardware needed and necessary long shutter speed do not allow for its systematic application in aerial reconnaissance, its general archaeological usefulness will currently be rather limited (certainly with the digital sensors nowadays found in D-SLRs) and can only be applied in cases a remotely controllable, stable aerial platform is provided.

6 ACKNOWLEDGEMENTS

This paper arises from the author's ongoing Ph.D. which studies the application of remote sensing in archaeological surveys. The research is conducted with permission and financial support of the Fund for Scientific Research - Flanders (FWO) and supervised by Professor dr. Frank Vermeulen (Department of Archaeology and Ancient History of Europe - Ghent University).

7 REFERENCES

Dorrell, P. G. 1994. *Photography in Archaeology and Conservation*. Cambridge, Cambridge University Press.

Eastman Kodak Company 1961. *Infrared and Ultraviolet Photography*. Rochester, Eastman Kodak Company.

Gibson, H. L. 1978. *Photography by Infrared: Its Principles and Applications*. New York, Wiley.

Hansell, P., Lunnon, R. J. 1984, Ultraviolet and Fluorescence Recording, in Morton, R. A., *Photography for the Scientist*, London, Academic Press, 321-354.

Har, D., Son, Y., Lee, S. 2004, SLR Digital Camera for Forensic Photography, in Blouke, M. M.., Sampat, N., Motta, R. J., *Sensors and Camera Systems for Scientific, Industrial, and Digital Photography Applications, V, 19-21 January 2004, San Jose, California, USA*, Bellingham, IS&T – SPIE, 276-284.

Lavigne, D. M. 1976. Counting Harp Seals with Ultra-Violet Photography, *Polar Record*, 18: 269-277.

Lavigne, D. M., Oritsland, N.A. 1974. Ultraviolet Photography: A New Application for Remote Sensing of Mammals, *Canadian Journal of Zoology*, 52: 939-941.

Matthews, S. K. 1968. *Photography in Archeology and Art*. London, John Baker.

Ray, S. F. 1999. *Scientific Photography and Applied Imaging*. Oxford, Focal Press.

Ray, S. F. 2002. *Applied Photographic Optics. Lenses and Optical Systems for Photography, Film, Video, Electronic and Digital Imaging*. Oxford, Focal Press.

Rørslett, B. 2004. *All You Ever Wanted to Know About Digital UV and IR Photography, But Could Not Afford to Ask*. www.naturfotograf.com/UV_IR_rev00.html (date of access: 22/07/2008).

Rørslett, B. 2008. *Lens Survey and Subjective Evaluations*. www.naturfotograf.com/lens_surv.html (date of access: 21/07/2008).

Spitzing, G. 1979. *Infrarood and ultraviolet fotografie*. Amsterdam Brussel, Focus.

Vecchia, P., Hietanen, M., Stuck, B.E., van Deventer, E., Niu, S. 2007. *Protecting Workers from Ultraviolet Radiation*. Oberschleißheim, International Commission on Non-Ionizing Radiation Protection.

Verhoeven, G. 2007, Becoming a NIR-Sensitive Aerial Archaeologist, in Neale, C., Owe, M., D'Urso, G., *Remote Sensing for Agriculture, Ecosystems, and Hydrology IX, Florence, Italy, 17-19 September 2007*, Bellingham, SPIE, 333-345.

Verhoeven, G. 2008a. Imaging the Invisible Using Modified Digital Still Cameras for Straightforward and Low-Cost Archaeological Near-InfraRed Photography, *Journal of Archaeological Science* (in Press).

Verhoeven, G. 2008b. It's all about the format – Unleashing the power of RAW aerial photography, *International Journal of Remote Sensing* (Submitted)

Verhoeven G., Loenders J. 2006. Looking through Black-Tinted Glasses - A Remotely Controlled Infrared Eye in the Sky, in Campana, S., Forte, M., *From Space to Place. 2nd International Conference on Remote Sensing in Archaeology. Proceedings of the 2nd International Workshop*, Oxford, Archaeopress, 73-79.

Verhoeven, G., Loenders, J., Vermeulen, F., Docter, R. 2008, Helikite Aerial Photography or HAP – A Versatile Means of Unmanned, Radio Controlled Low Altitude Aerial Archaeology, *Journal of Archaeological Science* (Submitted).

Vizy, K. N. 1974. Detecting and Monitoring Oil Slicks with Aerial Photos, *Photogrammetric Engineering*, 40: 697-708.

The combinatorial explosion: defining procedures to reduce data redundancy and to validate the results of processed hyperspectral images.

A. Traviglia

Department of Archaeology – Archaeological Computing Laboratory, University of Sydney, 2006, NSW, AUSTRALIA, atraviglia@usyd.edu.au

Keywords: MIVIS, hyperspectral images, image processing, image evaluation, GIS, Aquileia (Italy)

ABSTRACT:

This paper will focus on ways to manage large numbers of remotely sensed data images as results of image processing, a primary problem especially for those dealing with hyperspectral images that pose considerable issues due to the elevated number of channels. While briefly introducing the results of the application of several common image processing techniques in the target area of Aquileia (NE Italy), the current paper will discuss the necessity to define a set of procedures to reduce the number of final images to be used for visual inspection, selecting the ones that do not carry redundant information. Consequently, cross process coverage, detected traces evaluation and process validity tables will be presented and the results of their application discussed in order to provide information about how to reduce the images to a small number and be able to insure the complete coverage as regards to the detectable traces.

1. INTRODUCTION

The application of hyperspectral images in archaeological research in the last years has demonstrated that this kind of data can represent a valuable resource as a complementary source of information for archaeological goals. In the many projects using hyperspectral data, various processes are normally applied to part or to all of the image bands used for detection of archaeological features. When dealing with one or more of these images formed by a number of bands, which can be over a hundred, even considering realistically to use a small part of the bands for multiple processes, inevitably the result is an extremely large number of images that must be subjected to visual analysis and interpretation; at the same time, as a side problem, since many of the different processes produce similar results that provide the same traces, the number of repeatedly identified and recorded features can became too large.

The primary goal of the research project introduced here was to ascertain the usefulness of the MIVIS (Multispectral Infrared and Visible Imaging Spectrometer) images in the identification of unknown archaeological features in the case study area of Aquileia (Italy) and to establish how much these images could produce in terms of new archeological information. The process of exploitation of the spectral content of the MVIS data led to an unexpected issue to be faced, that is to say the overproduction of images that must be subjected to visual analysis and interpretation and the consequent elevated number of detected features. MIVIS is in fact a 102 bands image: even utilizing a minor number of the bands for simple TC/FC composites and for the several applied image processes, the combinatorial explosion created an almost unmanageable situation. Consequently it became critical to define a set of procedures to reduce the number of final images to be used for a visually performed interpretation of the imagery, selecting the ones that did not carry redundant information. Correlation and selection matrixes (Traviglia 2007: 295), comparison tables, cross process coverage tables were adopted on a test MIVIS run in order to define procedures to reduce the images to a smaller number and be able to insure the complete coverage as regards to the detectable traces. Only the most successful processes or composites were then adopted for the other MIVIS runs.

The set of chosen images has been managed through a GIS that provided also the archaeological and topographical data necessary to eventually recognize the detected surface features as ancient origin traces, attributing each of them a value of visibility and archaeological reliability as result of the interpretation process.

2. HYPERSPECTRAL IMAGES AND ARCHAEOLOGICAL INVESTIGATION

2.1 *The research project*

In the present research, the spectral content of the MIVIS images was used to reveal the presence of ground features related to archeological sites and structures under the ground surface on the basis of the different spectral characteristics of the terrain and of the vegetation. MIVIS is a simultaneous multispectral imaging system that operates in the wide range of wavelengths from visible to Thermal-IR regions of the spectrum, with a high spectral resolution and elevated number of channels (102). The runs are normally taken from a distance of around 1500-2500m from the Earth surface: based on flight altitude their pixel resolution is usually around 3x3m. The MIVIS images used in this research have been captured on two different days during October 1998 in two shots: a daytime shot (about h. 12 pm) and a so-called night shot (about h. 9-10 am). There are 10 runs that cover the target area, divided in 5 runs for each day or shot. Various processes have been applied to these images and their results compared in order to identify the ones that better match the different research targets. The goal of the enhancement techniques is to increase and improve the optic distinction between traces recorded in the scene and the surrounding areas by generating a new image where the useful information is more easily identifiable.

The case study area on which the MIVIS data have been tested included the Roman foundation town of Aquileia, located in NE Italy, and its surrounding countryside, comprising the neighboring Communes of Terzo d'Aquileia and Fiumicello.

2.2 Methodological approach to spectral analyses

Among the several processing methods the MIVIS runs have been subjected to in this project, the vegetation indexes (VI) have found prominence. As well known these indices can enable the identification of underground archaeological deposits that enhance or, in opposition, limit the growth of the vegetation. Heterogeneity of the texture of the subsoil has in fact a strong reflection on the growth of the vegetation, determining the appearance of the so called "crop-, grass-, or weed- marks". Various VI (such as DVI, NDVI, MSAVI2) have been calculated, tested, and compared to determine the best method for evaluating vegetation since different vegetation indices can work better for archaeological research, in accordance with certain environmental situations.

A specific Soil Index (SI) has been developed based on the study of the different degrees of water absorption to support the investigation of the numerous traces over non-vegetated zones: emphasizing the wetness or the dryness of a portion of the ground, it allowed the identification of feature on bare soil possibly related to underground structures (Traviglia 2005).

Due to the highly correlated nature of hyperspectral data, the Principal Component Analysis (PCA) was adopted to reduce the information previously contained in the original n-band data set into a smaller number of new bands that could be used in place of the original ones. However, in applying the most common procedure of visual inspection in PCA, consisting of generating a RGB false color composite of some of the principal components of a scene and increasing to 6 the number of used principal components, which have proven to convey significant information, 120 different combinations were generated losing the advantage of computing an "image reducing" process (Traviglia 2006: 126). In addition to the traditional PCA performance, a number of principal component images have been created through spectral subsets in order to convey only the information of spectral regions of interest.

A Selective Principal Component Analysis (SPCA) has been computed for groups of homogeneous bands belonging to different spectral regions or to different sensors' spectrometers. A selected number of the resulting images (originally 140 for each MIVIS run) has been then visually inspected using the chosen images both singularly and through their composites. Their selection was based on the intrinsic dimensionality (ID) of the data that led to a reduced number of 14 images and subsequently a correlation matrix was calculated in order to automatically identify in that group the best possible combinations that could carry the whole of the information (Traviglia 2007: 294-295).

Among the numerous forms of linear data transformations that have been developed for vegetation monitoring the Tasseled Cup Transformation, one of the most applied in archaeological studies, has been computed. The absence of specific coefficients for the calculation of a TCT for MIVIS data led to test a flow of operations in order to perform a modification of the MIVIS bands to make them applicable the same coefficients used to perform a Tasseled Cap Transformation over a Landsat ETM image. To do that, the MIVIS bands had to be converted into the same spectral coverage of a Landsat image, where possible. The first 3 axes of the resulting images from each run have been singularly visually inspected as well as their combinations (6 different composites for each run).

Finally, some of the most successful images delivering an elevated number of features have been obtained through the combination and display in RGB of different bands selected from different processes. The most interesting appeared to be the ones involving Tasseled Cap components, like for example the composite in RGB display of Tasseled Cap Brightness, NDVI and Tasseled Cap Wetness.

It is easy to understand that at the end of the processing activity and before starting the phase of inspection and interpretation of the images, the number of the images to submit to visual analysis, which included the single original bands, their simple combinations in true and false color composites, as well as all the described processes and the consequent derived composites, was extremely high.

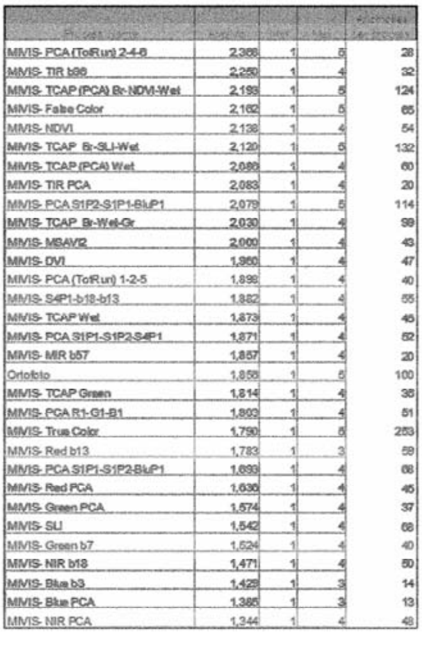
3. EVALUATING, COMPARING, SELECTING: THE IDENTIFICATION OF SUCCESFUL PROCESSES

Among the many possibilities that the integration of the MIVIS images in the GIS allowed, there is the opportunity to compare in quantitative and statistic ways the number of detected and digitized features in order to evaluate the potential of each performed process in terms of capability of emphasizing the traces. This leads to the identification of which process is more successful for reaching the set goals. Attributes have been assigned to every features digitized in the GIS in order support this comparison.

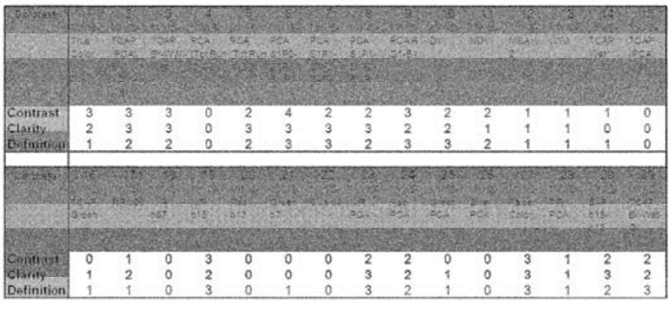
The processes can be evaluated from two points of view: from the point of view of the visibility of the traces they can provide and the point of view of the number of traces they allow to identify. Moreover they can be compared through the reciprocal coverage of traces they exhibit with one another.

3.1 Evaluation through "Visibility Index Table"

The visibility of a trace can be defined as the degree to which an object can be distinguished from the surrounding areas through the contrast that is realized in the digital images by significant difference of DN values of the pixels. In order to define which are the MIVIS images (image processes or simple visualizations) able to better emphasize or display the traces over the landscape, an index of visibility was created on the base of a visibility attribute conferred to each detected trace. The "Index of Visibility" of the anomalies is an index of the quality of visual appearance of the traces; it is evaluated through a scale of values from 1 to 5, where 1 indicates slight possibility to identify the trace and 5 means that the trace is extremely visible, independently of the type of surface materials surrounding the trace (bare soil or vegetation). In the GIS, one scale value is attributed to each identified trace for a given process. The Visibility Index Table (see below Table 1) lists, in order of highest score of average visibility, the MIVIS images that showed highest visibility of traces.



[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MIVIS- PCA (TotRun) 2-4-6	2,366	1	5	28
MIVIS- TIR b98	2,250	1	4	32
MIVIS- TCAP (PCA) Br-NDVI-Wet	2,193	1	5	124
MIVIS- False Color	2,162	1	5	65
MIVIS- NDVI	2,138	1	4	54
MIVIS- TCAP Br-SLI-Wet	2,120	1	5	132
MIVIS- TCAP (PCA) Wet	2,086	1	4	60
MIVIS- TIR PCA	2,083	1	4	20
MIVIS- PCA S1P2-S1P1-BluP1	2,079	1	5	114
MIVIS- TCAP Br-Wet-Gr	2,030	1	4	99
MIVIS- MSAVI2	2,000	1	4	43
MIVIS- DVI	1,960	1	4	47
MIVIS- PCA (TotRun) 1-2-5	1,898	1	4	40
MIVIS- S4P1-b18-b13	1,882	1	4	55
MIVIS- TCAP Wet	1,873	1	4	45
MIVIS- PCA S1P1-S1P2-S4P1	1,871	1	4	52
MIVIS- MIR b57	1,857	1	4	20
Ortofoto	1,856	1	5	100
MIVIS- TCAP Green	1,814	1	4	36
MIVIS- PCA R1-G1-B1	1,803	1	4	51
MIVIS- True Color	1,790	1	5	253
MIVIS- Red b13	1,783	1	3	59
MIVIS- PCA S1P1-S1P2-BluP1	1,693	1	4	68
MIVIS- Red PCA	1,636	1	4	45
MIVIS- Green PCA	1,574	1	4	37
MIVIS- SLI	1,542	1	4	68
MIVIS- Green b7	1,524	1	4	40
MIVIS- NIR b18	1,471	1	4	50
MIVIS- Blue b3	1,429	1	3	14
MIVIS- Blue PCA	1,385	1	3	13
MIVIS- NIR PCA	1,344	1	4	48



[illegible]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	True Color	TCAP PCA	TCAP [illegible]	PCA [illegible]	PCA [illegible]	PCA [illegible]	PCA [illegible]	PCA [illegible]	PCA R1-G1-B1	DVI	NDVI	MSAVI 2	[illegible]	TCAP Wet	TCAP PCA
Contrast	3	3	3	0	2	4	2	2	3	2	2	1	1	1	0
Clarity	2	3	3	0	3	3	3	3	2	2	1	1	1	0	0
Definition	1	2	2	0	2	3	3	2	3	3	2	1	1	1	0

[illegible]	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Green	[illegible]	b57	b18	b13	b7	[illegible]	PCA	PCA	PCA	PCA	Color	PCA	b18-	Br-Wet
Contrast	0	1	0	3	0	0	0	2	2	0	0	3	1	2	2
Clarity	1	2	0	2	0	0	0	3	2	1	0	3	1	3	2
Definition	1	1	0	3	0	1	0	3	2	1	0	3	1	2	3

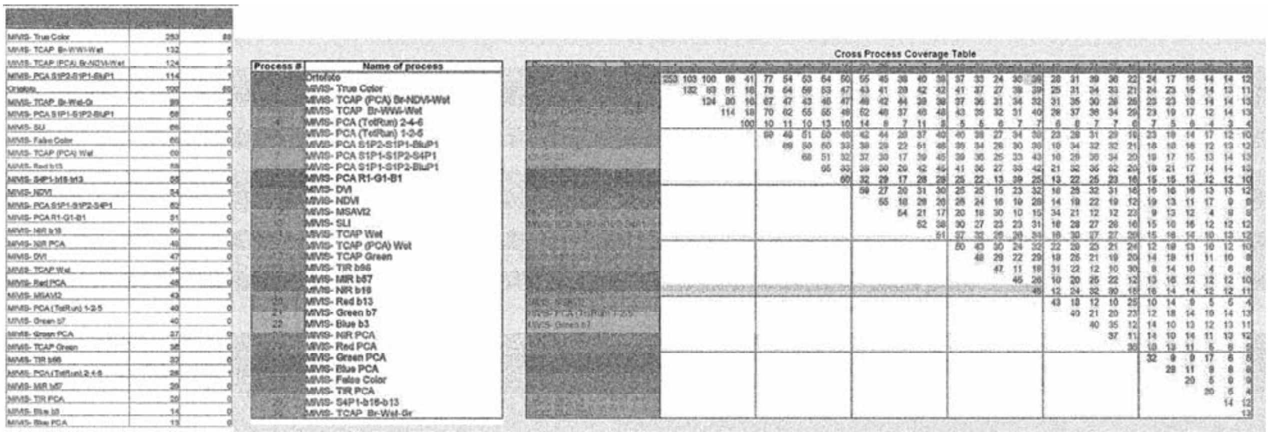
Table 1 (leftt). Average Visibility Index by process with min. and max. range included Table (right) 2. Contrast-clarity-definition table example: the values go from 0 up to 4, where 4 is the better level.

In the proposed example, the composite of the Principal Components 2, 4 and 6 (RGB display) of the PCA obtained using all the bands appears in that table to have the best absolute results in terms of the visibility. However, it must be made clear that this does not correspond to having a "clear", easily readable image; in actuality, this PC composite is very "difficult" to decode and one needs to have a very good knowledge of the area and of the traces that are there. In front of situations like this one, it became obvious that a more rigorous index was necessary. Another two attributes took part in the redefinition of the visibility: clarity and definition, where "clarity" refers to the sharpness of the boundaries of the traces and the "definition" refers to the homogeneity of pixel DN values within the trace. Thus, in order to really evaluate the success or failure of a process, meaning its readability, it is fundamental to have for each trace a related table of information about the compared qualities of contrast, clarity and definition (see Table 2), to give a realistic judgment even in situations where the contrast is very good, but the process clarity and definition are very poor.

Back to PCA 2-4-6, this process demonstrated to be able to create a strong contrast between the feature itself and what is surrounding it, but it was indispensable to know in advance where the specific trace was located. Consequently, PCA 2-4-6 does not allow the identification of a large number of surface features just by itself. For this reason, in interpreting the data, it is extremely important to compare the average of visibility allowed from a process with the total number of features identifiable through the process itself (see Table 2 and Table 3). In the case of the PCA 2-4-6, it is a low number, a clear demonstration that this image cannot be used by itself in a visual analysis for the research of surface features.

3.2 Evaluation through Per Process Trace Count Table

The second way to compare the processes is from the point of view of the number of traces they allow to identify. In Table 3 (left) it is shown how the image processes or simple displays of images work in terms of identifying surface features. In this case, there is not a judgment on the quality of the visibility of the trace, so, even if True Colors images have shown to allow the identification of the highest number of features, the quality of definition, contrast and clarity of features is not always the best and the display of the same trace in other processes is needed to better identify the contours of the trace itself. True Color images, in any case, have demonstrated to be necessary to guide the process of identification of anomalies, because the comparison of the processed images with a True Color display image allows to determine the possible nature of the feature.



MIVIS- True Color	253	89
MIVIS- TCAP Br-WWI-Wet	132	6
MIVIS- TCAP (PCA) Br-NDVI-Wet	124	2
MIVIS- PCA S1P2-S1P1-BluP1	114	1
Ortofoto	100	89
MIVIS- TCAP Br-Wet-Gr	89	2
MIVIS- PCA S1P1-S1P2-BluP1	68	0
MIVIS- SLI	66	0
MIVIS- False Color	60	0
MIVIS- TCAP (PCA) Wet	60	0
MIVIS- Red b13	58	1
MIVIS- S4P1-b18-b13	55	0
MIVIS- NDVI	54	1
MIVIS- PCA S1P1-S1P2-S4P1	52	1
MIVIS- PCA R1-G1-B1	51	0
MIVIS- NIR b18	50	0
MIVIS- NIR PCA	49	0
MIVIS- DVI	47	0
MIVIS- TCAP Wet	45	1
MIVIS- Red PCA	45	0
MIVIS- MSAVI2	43	1
MIVIS- PCA (TotRun) 1-2-5	40	0
MIVIS- Green b7	40	0
MIVIS- Green PCA	37	0
MIVIS- TCAP Green	36	0
MIVIS- TIR b96	32	0
MIVIS- PCA (TotRun) 2-4-6	28	1
MIVIS- MIR b57	29	0
MIVIS- TIR PCA	20	0
MIVIS- Blue b3	14	0
MIVIS- Blue PCA	13	0

Process #	Name of process
	Ortofoto
	MIVIS- True Color
	MIVIS- TCAP (PCA) Br-NDVI-Wet
	MIVIS- TCAP Br-WWI-Wet
4	MIVIS- PCA (TotRun) 2-4-6
	MIVIS- PCA (TotRun) 1-2-5
	MIVIS- PCA S1P2-S1P1-BluP1
7	MIVIS- PCA S1P1-S1P2-S4P1
	MIVIS- PCA S1P1-S1P2-BluP1
	MIVIS- PCA R1-G1-B1
	MIVIS- DVI
	MIVIS- NDVI
12	MIVIS- MSAVI2
13	MIVIS- SLI
	MIVIS- TCAP Wet
	MIVIS- TCAP (PCA) Wet
	MIVIS- TCAP Green
	MIVIS- TIR b96
	MIVIS- MIR b57
	MIVIS- NIR b18
20	MIVIS- Red b13
21	MIVIS- Green b7
22	MIVIS- Blue b3
	MIVIS- NIR PCA
	MIVIS- Red PCA
	MIVIS- Green PCA
	MIVIS- Blue PCA
	MIVIS- False Color
	MIVIS- TIR PCA
29	MIVIS- S4P1-b18-b13
	MIVIS- TCAP Br-Wet-Gr

Cross Process Coverage Table

Table 3 – (left) Total number of traces for each process including unique recognitions. -Cross process coverage table (right). ID process number (center).

The Tasseled Cap appears to be one of the most useful processes to identify features, if used for producing composites of different images: the Tasseled Cap processes employing combinations of images in RGB display are in fact localizable in the upper part of the index, while the single components of the same process are located in lower part of the index. Also, in this index the Near Infrared band or the processing involving its use are placed in the middle-upper level, as it was in the Visibility Index Table, confirming its good efficiency. Low efficacy is shown from Green bands and the corresponding SPCA; the thermal band 96, seen at the second place in the Visibility Index Table, is here in the lowest levels, showing how, even if being good for highlighting the shape of traces, it is not for detecting the traces themselves on the image. The least effective images are the simple displays of single original bands or the relative SPCA: it is not surprising that in the worst levels the Blue band and the SPCA of Blue can be found, since the blue band has already demonstrated the scarce usefulness, being blurred from atmospheric scattering.

3.3 Coverage between image processes

Another way to compare the results obtainable from the processes is to look at the coverage between processes, comparing the number of traces common to two given processes against the total of one of the processes. This is possible through a table listing the traces found in a process versus the number of those specific traces also found in other processes. For example, 39 of the 253 traces visible in True Colors are also seen in SPC of Red bands: this gives SPC Red about 15% coverage over True Colors. Reversing it, this means that 39 of the 45 traces found in SPC Red are also seen in True Colors, giving True Colors about 87 % coverage over SPC Red (Table 3, center and right).

4. CONCLUSIONS

At the beginning of the research problem the issue of a combinatorial explosion of the produced images and obtained detected traces was not sufficiently estimated. This led, in the progress of the work, to the definition of a complex GIS architecture able not only to manage archaeological and topographical data through overlay but also to support the selection of valid image processes delivering useful and original information. The GIS has played a critical role in reducing the processing time by indicating in the first stage the successful techniques that should be adopted. It is evident however that the obtained results can only be considered valid in relation to the used data and that new tests must be performed when using different data and examining environments with different characteristics from the ones here presented.

5. REFERENCES

Traviglia, A. 2005. A semi-empirical index for estimating soil moisture from MIVIS data to identify subsurface archaeological sites, in *9° Conferenza Nazionale ASITA, Federazione delle Associazioni Scientifiche per le Informazioni Territoriali ed Ambientali, 15-18 Novembre 2005, Catania, Atti Volume II.* Catania, ASITA, 1969-197.

Traviglia, A. 2006. Archaeological usability of Hyperspectral images: successes and failures of image processing techniques, in Campana S., Forte M. (Eds.), *From Space to Place. Proceedings of the 2nd International conference on Remote Sensing in Archaeology*, *Rome, Dec. 4-7 2006.* Oxford, Archaeopress, 123-130.

Traviglia, A. 2007. MIVIS Hyperspectral Sensors for the Detection and GIS Supported Interpretation of Subsoil Archaeological Sites, in Clark J.T., Hagemeister E. (Eds.), *Digital Discovery: Exploring New Frontiers in Human Heritage. CAA 2006. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 34th Conference, Fargo, United States, April 2006,* Budapest, Archaeolingua, 287-299.

3

Active airborne and satellite sensors (lidar, SAR): data processing and applications

Satellite Systems devoted to Earth's Remote Sensing: a tool for Archaeological Applications

F. Vespe[1], G. Milillo[1], G. Lacicerchia[2]

1 Agenzia Spaziale Italiana-Centro di Geodesia Spaziale- 75100 Matera, 75100, Italy, francesco.vespe@asi.it

2 Consorzio Craco Ricerche, Craco (Mt), 75010, Italy

Keywords: SAR, GPS, Remote Sensing, Earth's Satellites,

ABSTRACT: In the last 20 years a lot of satellites devoted to Earth's observation have been launched. Currently the huge amount of Remote Sensing satellites are going to make them suitable also for end user applications other than for scientific investigations. Furthermore also satellite systems initially designed for other applications, namely Global Navigation Satellite Systems like GPS or future GALILEO, have a wide application in the field of Earth's Remote Sensing (hereafter ERS). Thus in the first part of the present paper we will discuss the possible applications of ERS based on radar systems (SAR). At this purpose ASI is launching a constellation of 4 satellites fully devoted to ERS by using just the SAR technique. In the second section applications of ERS based on GNSS systems will be described. Finally their potential application in the field of Archeology will be outlined.

1 SAR SYSTEMS

The Italian Space Agency (hereafter ASI) is currently launching a constellation of 4 satellites devoted to Remote Sensing named Cosmo Sky Med (hereafter (CSK). The system has the ambitious plan to move from scientific investigations to cover user civilian as well as defense applications. It is a dual use systems. For what concern the civilian applications CSK will be able to cover the areas sketched in Fig. 1

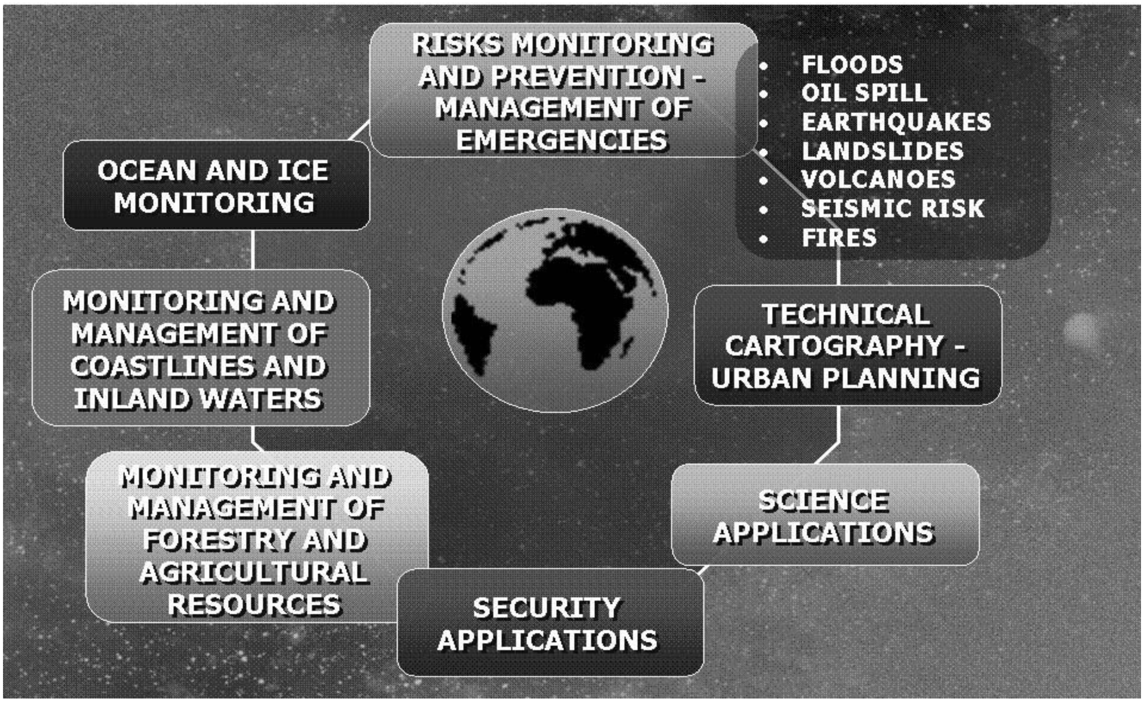

RISKS MONITORING AND PREVENTION - MANAGEMENT OF EMERGENCIES
FLOODS
OIL SPILL
EARTHQUAKES
LANDSLIDES
VOLCANOES
SEISMIC RISK
FIRES
OCEAN AND ICE MONITORING
MONITORING AND MANAGEMENT OF COASTLINES AND INLAND WATERS
TECHNICAL CARTOGRAPHY - URBAN PLANNING
MONITORING AND MANAGEMENT OF FORESTRY AND AGRICULTURAL RESOURCES
SCIENCE APPLICATIONS
SECURITY APPLICATIONS

Fig. 1. Areas of applications which CSK plans to serve (see Coletta 2008)

The resolution of the system is at 1 meter level using a frequency of 9.6 GHz. In figure 2 an image of Pompei remnant is shown reconstructed with CSK SAR. The full constellation will consist of four satellites put on the same polar orbit with a separation of 90° in true anomaly. Currently 2 CSK satellites are in flight.

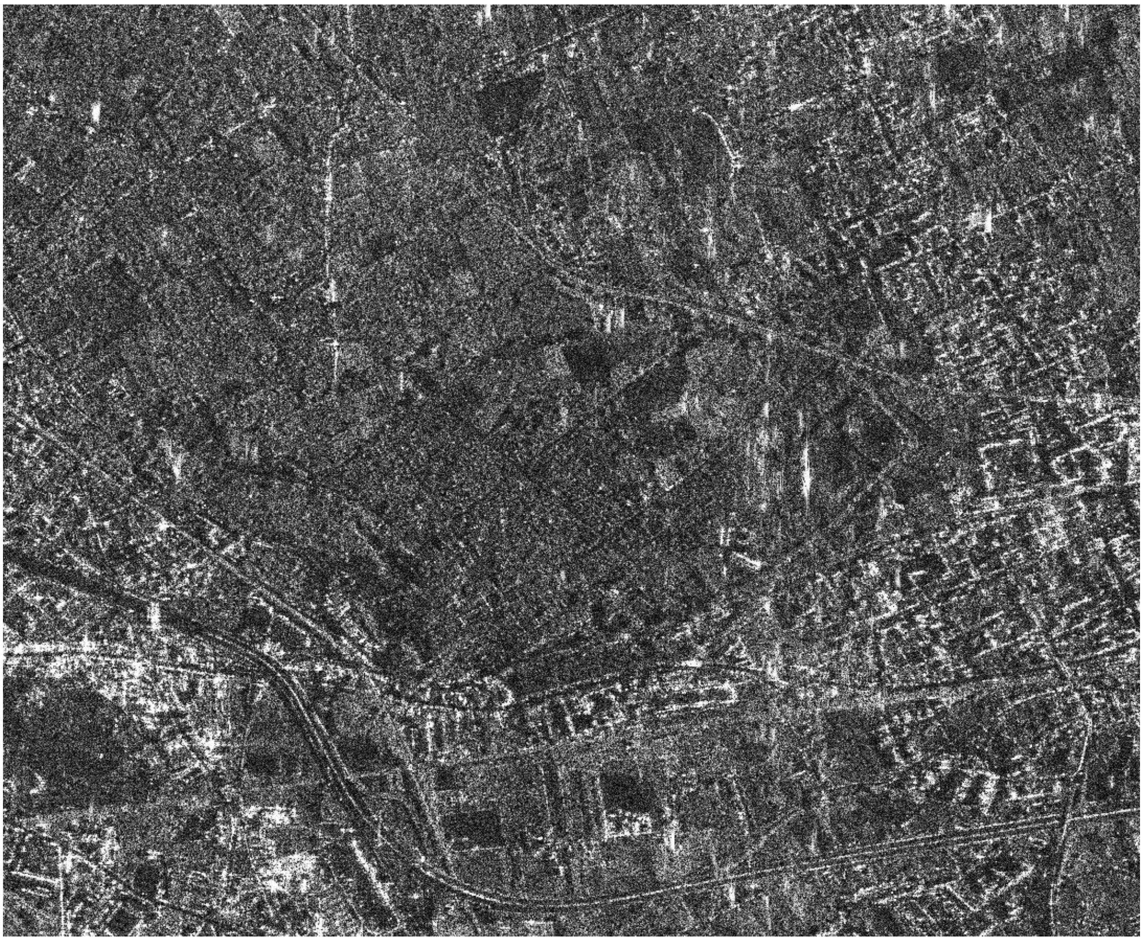


Figure 2. A spot image of Pompei taken with the radar on CSK.

With the final configuration CSK will be able to have a revisit time of 3 h which will make suitable the SAR technique for early warning applications as well. The application of Interferometry SAR technique as well as that of permanent scatter (Ferretti et al. 1999 & 2000) allow to detect ground deformation at millimeter level.

2 GNSS SYSTEMS

The Global Positioning System was conceived mainly for navigation and positioning applications. It was a dual use system with a dramatic degradation of the performances of the system for civilian applications. The real time navigation performances allowed to civilian are indeed ten time worse than for defense purposes. For all the scientific research and the use of the system in differential mode the system currently is able to provide coordinates of a point on Earth with a precision of few millimeters in post-processing mode. So a wide field of applications in field of Geodesy, Geophysics, Atmosphere and Ocean Physics are currently covered by the use of GNSS signals which in part overlaps the applications of CSK. Thus in fig. 3 some results of seismic monitoring by using GPS is shown. Essentially GPS is able to measure the strain rate of the Earth’s crust.

The strain rates can be computed also for huge building infrastructures like bridges, dams or archeological ones. In fig 4 it is shown how a GPS network is able to monitor a landslide area. In less than an hour GPS is able indeed to detect displacements of 2-3 cm. In fig. 5 it is shown how the use of GPS is able to forecast severe meteorology events. It was widely demonstrated that GPS network are able to improve the forecasting on regional basis making the system particularly suitable for agro-meteorology purposes. In Fig. 6 is described how to use GPS for monitoring the sea level. The tide gauges measure the relative displacements of the sea level against the ground; while the GPS is able to determine the absolute movements. Thus placing a receiver on the rod of a tide gauge it is possible to single out the absolute sea level variations

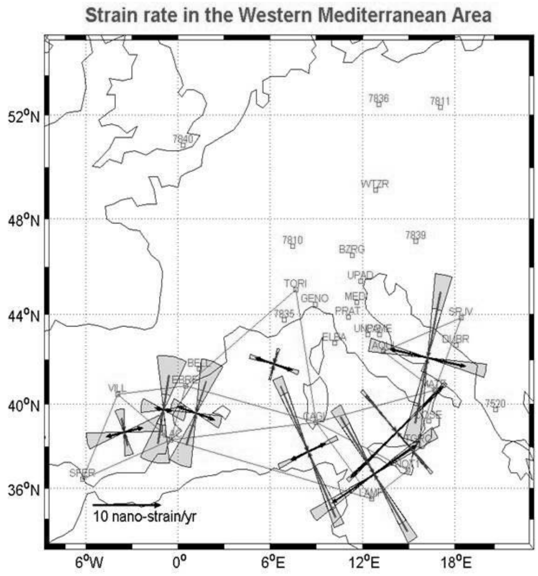


Figure 3. Strain rate computed by using the coordinates of a GPS network in the Mediterranean Area.

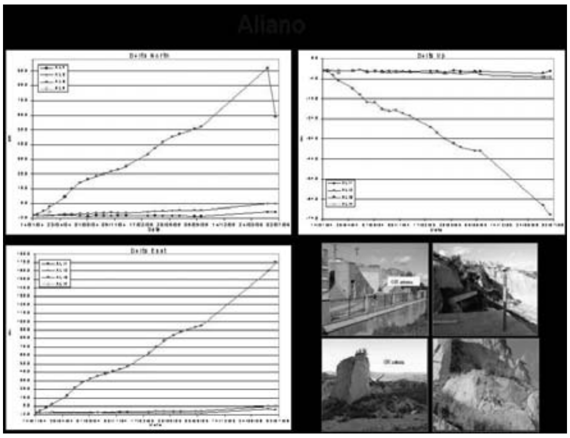


Figure 4. Landslide movements measured with a GPS network. In two years a displacements were detected of about 1 m and 2 m in turn along the UP and the East component.

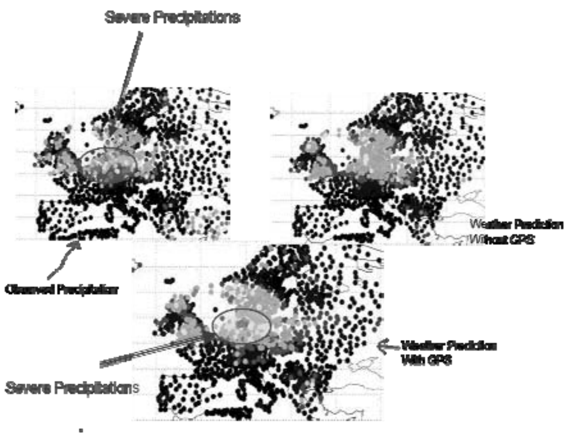


Figure 5. The use of GPS for meteorology forecasting. The figure shows how GPS network improves the numerical Weather Predictions when severe meteo events occur

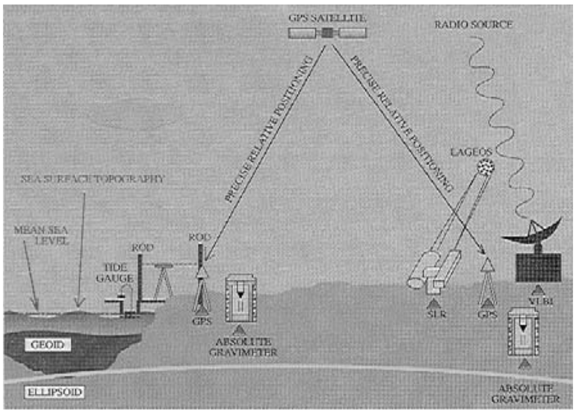


Figure 6. GPS is helpful to determine the sea level and topography combined with other satellites technique (radar-altimeter). The sea level monitoring is important not only for global change investigations but also for the protection of urban areas of artistic interest like Venice

3 . ARCHEOLOGY PROJECTS BASED ON SATELLITE SYSTEMS

The capabilities of ERS as well as GNSS satellites to detect deformations and coordinates at sub-centimeter level of the Earth's surface have made space systems a very promising tool for investigate and monitor outdoor sites of archeological interest. Thus for example the capability to monitor the sea level and topography can be helpful for decision makers to find solutions to protect cities of cultural interest like Venice. SAR technique could be helpful in principle to find archeological remnants or monitor surface deformations of whole areas of cultural interests.

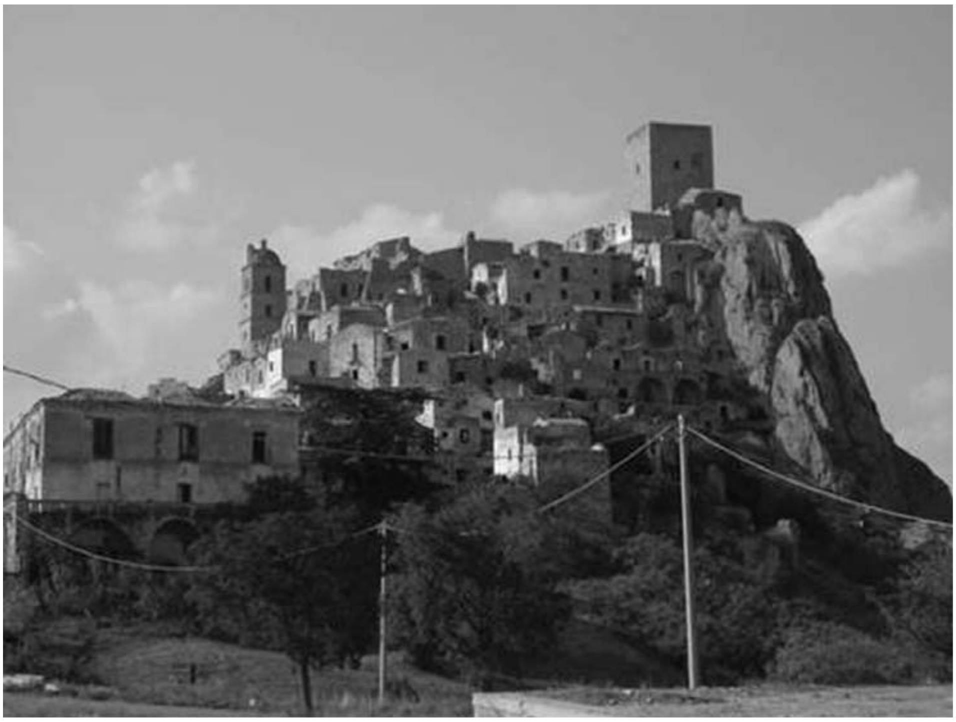


Fig. 7. Craco town currently surveyed by using a GPS network

ASI is undertaking some projects for the monitoring of sites of cultural interest. Craco, a small town in South Italy –see fig. 7 - represent a good test site. It suffered a huge landslide in the sixties which forced all the people to leave the town. ASI started last year to monitor the area in collaboration with consortium Craco ricerche. A GPS network was established last year on that area just to monitor the landslide progress . We plan to double the GPS survey with SAR observations.

Furthermore ASI is working on a Memorandum of Understanding (MoU) with World Monument Found. The MoU will define some sites in the world of archaeological interest to monitor with satellite techniques.

REFERENCE

Coletta, A. 2008. The COSMO-SKY-MED program, International Aerospace Exibition, Farnborough 16/07.

Ferretti, A., .Rocca, F., .Prati, C. 1999.Permanent scatterers in SAR Interferometry in *Proc. IGARSS'99*, (Hamburg, Germany,) Jun 28 - Jul 02.

Feretti, A., Prati, C., Rocca, F. 2000. Permanent scatterers in SAR interferometry, *IEEE TGRS.* 39 (1) : 8-20, Jan.

Hydrologic History of the Eastern Sahara from Imaging Radar: A Framework for Archaeological Exploration

T. G. Farr[1], R. G. Blom[1], P. Paillou[2]

1 Jet Propulsion Laboratory, California Institute of Technology, email: tom.farr@jpl.nasa.gov.

2 Observatoire Aquitain des Sciences de l'Univers, UMR 5804, Floirac, France

Keywords: Radar, topography, ASTER, Sahara, subsurface

The region of the Gilf Kebir has never been thoroughly mapped in terms of the landforms and subsurface signs of past climates conducive to human occupation. As part of ongoing work and through a new proposal to NASA, we plan to generate new maps of the paleohydrology, topography, geomorphology, and surficial deposits of the area and develop GIS-based models which use the data to pinpoint past resources and travel pathways. The maps we are generating will constitute a unique resource for exploration for archeological sites in the Gilf Kebir and other regions of N Africa.

That the Sahara was favorable for human habitation at times has long been known. With the remarkable paleo-landscape revealed by the L-band (25 cm) Shuttle Imaging Radar-A in 1981, it became clear that ancient humans concentrated along integrated drainage systems dubbed “radar rivers” by McCauley et al. (1986). However SIR-A and subsequent long-wavelength radar coverage was limited and regional understanding of the drainage network has remained elusive. A complete map of the buried channels of the region could also prove useful for development of water resources (Robinson *et al.*, 2006; El-Baz *et al.*, 2007). [See also session on Mapping Subsurface Geology].

We are mapping the area with three sensors optimized for mapping and characterizing arid regions: The Japanese PALSAR L-band imaging radar, NASA’s SRTM, and ASTER (figure 1). Together these sensors will allow characterization of surface and subsurface landforms formed and modified by former wetter climates. A mosaic of PALSAR images will use as a base the topographic map produced by the Shuttle Radar Topography Mission, flown in 2000 (Paillou *et al.*, 2008). SRTM also produced C-band images, similar to those being produced by Europe’s ERS and Envisat and Canada’s Radarsat satellites which, despite their shorter wavelength (5.5 cm) and thus decreased penetration capability, have been used for mapping Sahara drainages (El-Baz et al., 2007). An advantage of the SRTM C-band images is that they are inherently registered to the topographic data and provide full, mosaicked coverage (figure 1b).

A third data set, visible-near infrared (VNIR) to thermal IR (TIR) images from ASTER, is being used mainly for mapping surficial landforms and vegetation. These wavelengths are sensitive to surface composition including rock types, weathering phenomena, and soil types (figure 1a). Vegetation also shows up well in near IR images. A unique capability of ASTER is the inclusion of several thermal IR bands. These allow increased sensitivity to composition, especially silica content, but also are capable of detecting thermal properties of the near-surface volume. Night-time thermal images have been shown to be sensitive to the bulk properties of the near-surface such as density and moisture content, as these determine the cooling rate (figure 1c). Combined with day-thermal images and a measure of the visible-wavelength albedo, thermal inertia, a quantitative measure of the thermal properties of a material can be derived.

Archaeologists have never had a synoptic view of the region around Gilf Kebir. In addition, the national governments of the region need a detailed map of landforms and resources for upcoming conservation efforts. The data and maps produced by this study will be unique and will be used for many years as a base for further studies of the archaeology of the region as well as other applications in hydrology, ecology, geomorphology, and tourism.

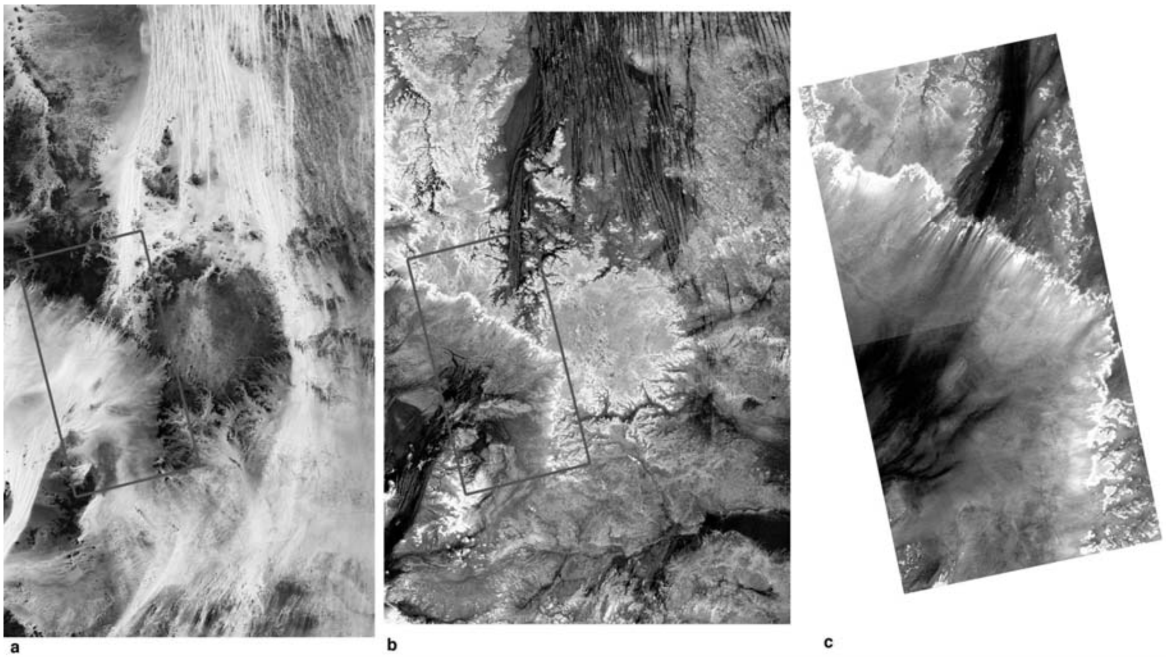


Figure 1. Images of the Gilf Kebir, Egypt.

a) Landsat Thematic Mapper mosaic from GeoCover 1990 (https://zulu.ssc.nasa.gov/mrsid/). Sand covered areas are easily discriminated from rocky areas. Other color variations reflect differences in composition of rocks and weathering products. Area covered is from 22-25° N, 25-27° E.

b) SRTM radar image mosaic of same area as a. Sand areas are generally dark except for thin covers of sand, which are penetrated by C-band (5.5 cm) radar. Some drainage paths shown here are buried by dry sand.

c) ASTER thermal IR image acquired at night. Note sandy areas are dark as their low thermal inertia allows them to cool faster than the rocky areas at the cliff edge. Area of image is shown in boxes in a) and b). Image acquired 20 October 2004.)

REFERENCES

El-Baz, F., Robinson, C.A., Al-Saud, T.S.M. 2007. Radar images and geoarchaeology of the eastern Sahara, ch. 2 in Wiseman and El-Baz, 2007.

McCauley, J.F., Breed, C.S., Schaber, G.G., McHugh, W.P., Issawi, B., Haynes, C.V., Grolier, M.J., El Kilani, A. 1986, Paleodrainages of the eastern Sahara- the radar rivers revisited (SIR-A/B implications for a mid-Tertiary trans-African drainage system), *IEEE Trans. Geosci. Rem. Sens*., 24: 624-648.

Paillou, Ph., Farr, T., Rosenqvist, A., Lopez, S. 2008, A PALSAR mosaic of Sahara to map subsurface geology, IGARSS ’08, Boston, MA.

Robinson, C., El-Baz, F., Al-Saud, T.S.M., Jeon, S.B. 2006, Use of radar data to delineate paleodrainage leading to the Kufra Oasis in the eastern Sahara, J. *African Earth Sci*., 44 : 229-240.

High resolution LiDAR for the recording of archaeological monuments & landscapes

A. Corns, R. Shaw

The Discovery Programme, Dublin, Ireland, Anthony@discoveryprogramme.ie, Robert@discoveryprogramme.ie

Keywords: LiDAR, Archaeology, DTM, 3D Modelling, High Resolution

ABSTRACT.

Over the past 16 years the Discovery Programme; an Irish archaeological research organisation, has strived to produce accurate high resolution 3-dimensional models of earthwork monuments and their archaeological landscapes. Initially this was achieved by the use of terrestrial based survey technologies including total stations and RTK GPS. However, this is a slow, labour intensive way to build such models, and often the final archaeological models were devoid of their landscape context. In 2003 the Discovery Programme implemented to great effect the use of digital aerial stereo photogrammetry in the creation of landscape and monument 3-dimensional models and associated orthoimages. However, problems including: the occlusion of features due to vegetation cover, and the great effort and expertise needed to process the data were evident.

Since the development of fixed wing LiDAR (Light Detection and Ranging), and its ability to rapidly produce landscapes Digital Terrain Models (DTM) even beneath vegetation, the Discovery Programme has monitored its application to the recording of archaeological features. Although impressive results have been seen from many examples of landscape modelling, the resolution and accuracy of the sensor devices (1m and 15cm respectively) often falls short to effectively record the subtle details and relationships of complex archaeological features.

Since 2007 the Discovery Programme has employed the use of a new aerial LiDAR system:

FLI-MAP 400 from BKS Surveys Ltd. (UK) and Fugaro Ltd. (Netherlands). This technology has several advantages in that it is helicopter mounted, allowing for relatively slow air speeds and low altitude flight paths which result in the collection of extremely high resolution height data(10cm). The FLI-MAP 400 system is equipped with three 150khz Laser scanners (forward – nadir – aft), that have a range accuracy of 1cm (1 sigma) and several imaging devices including high resolution mapping camera and three video cameras accompanying each laser scannerThis technology has been successfully implemented on three archaeological sites: Newtown Jerpoint abandoned medieval settlement, Dún Ailinne prehistoric hillfort and the Hill of Tara archaeological complex. This paper illustrates the results of these surveys, and the high level of terrain and monument detail recorded. Discussion includes the processing required to produce the final models and the level of vegetation removal that can be achieved from the multiple return signals of the LiDAR pulse. Examples are employed where the resulting terrain models are interpreted with additional field inspection to fully enable the understanding of the archaeological features and structures. Subsequent interpretations are then used in conjunction with the high resolution models to enable the realistic visualisation of monument and landscape features. Finally a look at the economic viability of such survey methodologies is placed into context when compared again high accuracy terrain based survey methods.

1. INTRODUCTION

Since its inception in 1992, The Discovery Programme has employed ground based survey technologies and methodologies for the 3-dimensional recording of archaeological monuments. Initially these technologies provided suitable solutions, however, the lack of context for many of the surveys and the high level of time investment required limited their use. The advent of aerial based LiDAR, with its rapid collection of topographic data offered a new approach to mapping and identifying archaeological features in their wider landscape context. This paper discusses the application of a particularly high resolution LiDAR system, FLIMAP 400, for the 3-dimensional recording of archaeological sites and landscapes.

2. THE EVOLUTION OF 3-DIMENSIONAL ARCHAEOLOGICAL SURVEY

Since the advent of the total station the ability to record the cultural components of the landscape in 3-dimensions has been employed by many archaeological surveyors over the past three decades. Initially utilizing traditional ground survey technologies of total stations and later RTK GPS, the capacity to record the subtle morphological remains of human activity on the landscape has been a powerful tool to aid archaeological investigators to unravel the evolution and functions of archaeological sites using non destructive methods (Bowden, 1999). Examples such as the topographic survey of the Hill of Tara completed in 1996 highlighted the effectiveness of the techniques in identifying new monument features (Newnam, 1998). However, due to the intensive level of field collection required to create a successful topographic model (Corns & Shaw, 2004) the extent of the surveys often fail to record the 3D component of the wider landscape that often provides the monument with its valuable context.

To resolve many of the inherent limitations of ground based survey methods, efforts were made to adopt the techniques of aerial photogrammetry which for decades have been employed to great effect by the national land mapping bodies. The Discovery Programme tested this approach on a variety of sites and the resulting 3-dimensional digital surface models (DSM) and associated orthophotographs have been well received by the archaeological community. The detailed recording of archaeological complexes with their landscape environ is a major improvement on ground based survey. However, having applied the technology to a number of archaeological surveys several limitations were identified. The ability to create detailed 3-dimensional models of an equivalent resolution to those produced by traditional ground based survey methods was limited. Many relict landscape features within Ireland are in grass or pasture lands, and the ability for the automated pixel matching routines to differentiate between the similar greens was problematical. Often to automatically generate a DSM, large pixel correlation matrices were employed, effectively lowering the resolution of the final 3-dimensional models. Although photogrammetry reduced field survey time, the level of computer based effort required to create and edit the DSMs through the digital photogrammetric process was large. Finally, this process was also not applicable to archaeological surveys where forestry was dominant due to the inability of the technique to record land surfaces beneath the vegetation canopy.

3. THE BIRTH OF LIDAR

With the advent of LiDAR technologies (Light Detection And Ranging), the ability to record from the air the topography of vast swathes of landscape remotely was now available to the archaeological surveyor. Many research projects (Doneus, M. and Briese, C., 2006a, Bewley, R. H., Crutchley, S. and Shell, C. A., 2005) have powerfully illustrated the potential for this technology to record the archaeological landscape 3-dimensionally, including those areas of terrain beneath tree cover (Doneus & Briese, 2006b). Another factor that has made the application of this technique advantageous is the relatively short time period between the commissioning of a survey to the creation of the final functioning Digital Terrain Models (DTM). Usually the horizontal and vertical accuracies of the final data models are 0.6m and 0.15m respectively (Boyda & Hillb, 2007). These values are suitable for topographic modelling of archaeological landscapes. However, the ability of this technology to successfully depict all the subtle features of an individual monument is questionable. As height point resolution is based upon the frequency of the LiDAR sensor and the air speed of the sensor platform, fixed wing LiDAR have the disadvantage that the speed of the plane can only be reduced to such a point before stalling occurs.

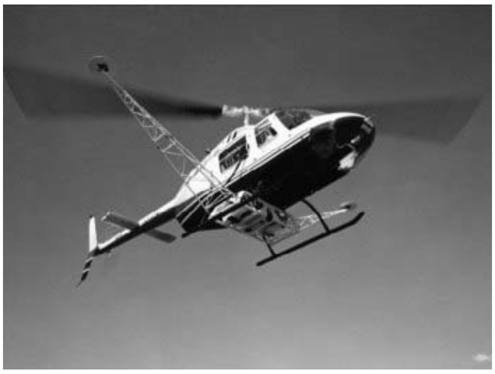


Figure 1. FLI-MAP 400 Helicopter LiDAR system (Fugro)

Range	< 300m
Altitude	40 - 400m
Laser Frequency	3 X 150 kHz lasers (7° forward, nadir, 7° aft)
Scanning Angle	60°
Accuracy (relative)	Horizontal 5cm Vertical 3cm
Multiple Returns	4
Positioning	2 RTK GPS
Imaging	11 Mega pixel still DV

Table 1. Summary of FLI-Map 400 technical details

4. APPLICATION TO ARCHAEOLOGICAL SURVEY

The opportunity to apply FLI-MAP 400 LiDAR technology to an archaeological landscape was presented to the Discovery Programme through the funding of two surveys: Newtown Jerpoint abandoned medieval settlement in Co. Kilkenny and Dún Ailinne prehistoric hillfort in Co. Kildare by the Heritage Council. Both sites consisted of multiple earthwork features and in the case of Dún Ailinne much of the important features are beneath vegetation cover. Two different resolutions were implemented for each survey (Newtown Jerpoint 50 pts/m², Dún Ailinne 15-30 pts/m²) to establish the required resolution to successfully record subtle topographic features.

On first inspection the resulting point cloud data sets indicated that the level of detail recorded was superior to traditional ground based survey methods, with significant levels of penetration through the vegetation layer. Several stages of data processing were carried out by BKS before final surface models were created. These included: 1. Transformation of data to WGS84 & Irish Grid coordinates, 2. Production of tiled ASCII DSM, 3. Removal of vegetation, buildings and above surface features using a combination of intensity and video inspection, 4. Production of tiled ASCII DTM

Both DSM and DTM ASCII datasets for each site were tiled to enable surface models to be created as the total point numbers were unmanageable (Newtown Jerpoint 30 million pts, Dún Ailinne 40 million pts). Surface models were created using ArcGIS 9.2 including 3D Analyst and Spatial Analyst extensions. Firstly TIN models were created from each tile ASCII xyz data set. These were subsequently rasterised to improve display performance and merged into a single seamless DTM and DSM. Hillshade analysis of the generated surface was carried out to aid the identification and description of archaeological features. The production of the hillshade models emphasised the level of detail that was being recorded using this technology. Low relief features such as wheel track marks were evident upon the surface modes. In addition to the DTM and DSM data orthoimages covering the complete survey area were supplied.

These two ventures proved this technology was highly suitable for the 3-dimensional recording of archaeological monuments and their landscape context. With further support from the Heritage Council the Hill of Tara archaeological complex in Co. Meath was chosen as the next site to apply the technology. The final DSM and DTM produced spectacular results (see figure. 3). Subtle archaeological features presented themselves with such clarity including the large circular henge structure that was discovered using geophysics (Fenwick & Newman, 2002), but little surface evidence was thought to exist. Serious time is now required to fully interpret these models. Initial analysis has already identified the evidence for palaeo-stream features that align with a spring/well monument to the south of the main complex.

To effectively visualise the resulting DSM and DTMs hillshade processing based upon multiple light sources correlated to the frequency of relief features was implemented (Loisios, Dimitrios, Tzelepis, Nikolaos and Nakos, Byron, GETYEAR). The resulting model has optimal lighting conditions to enable the identification of archaeological features. Experimentation of realistic visualisation was also carried utilising Eon Vue 6 software, the resulting images however failed to have the same impact as a simple grey coloured hill-shade model

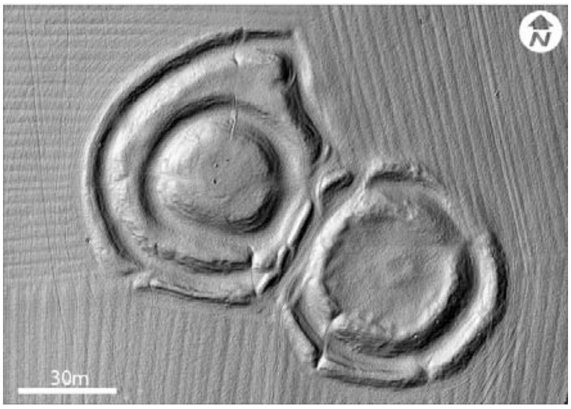


Figure 2. LiDAR derived hillshade of earthworks at Tara

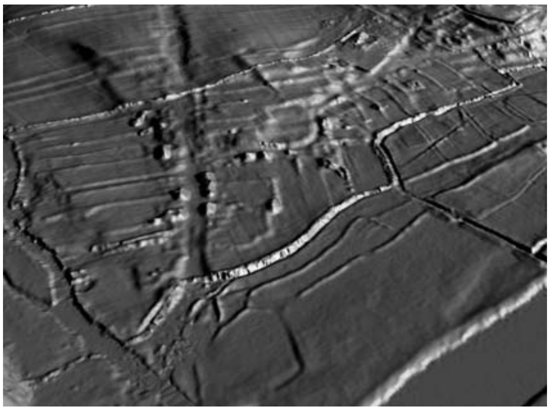


Figure 3. 3D view of Newtown Jerpoint LiDAR data

5. ECONOMIC COMPARISSONS

Initially the cost of each of these surveys was thought to be prohibitively expensive, but with reflection and comparison to the true costs of carrying out an equivalent survey using ground based survey technologies (GPS/Total station) the economic effectiveness of this technology to survey large monument complexes is clear. Table 2 summarises the equivalent cost of carrying out the survey of the Hill of Tara using ground based methods for a 1m resolution model, an appropriate sample distance for ground based surveys and a 12.5cm resolution model, equivalent to the LiDAR data. These values are based upon the total costs of a landscape surveyor/s with a daily recording rate of 2000 points.

Survey Method	Total Cost
12.5cm LiDAR Survey	*€40,000*
1m Ground based Survey	*€337,000*
12.5cm Ground based Survey	*€26,500,000*

Table 2. Comparative survey cost of LiDAR vs conventional ground based survey methods

6. CONCLUSION

Until recently the use of LiDAR for the topographic survey of archaeology has been limited to small scale features or archaeological landscapes. With the application of the FLI-MAP 400 helicopter based LiDAR the subtle features of archaeological monuments can now be recorded within similar accuracies to ground based survey techniques but with a much greater level of resolution and definition. The resulting DTM and DSM surfaces enable the identification of new features and a more detailed record of those already recognized. Finally in comparison, the economic viability of implementing this technology as the primary data collection method for 3-dimensional archaeological surfaces is clear.

7. ACKNOWLEDGEMENTS

All of the work carried out has been funded by the Heritage Council, Ireland and in particular the support of Ian Doyle. Continued assistance for the staff at BKS, especially John McNally has made this research process as straight forward as possible.

8. REFERENCES

Ackermann, F., 1999. Airborne laser scanning: present status and future expectations. *ISPRS Journal of Photogrammetry and Remote Sensing*, 54(2-3): 64-67.

Bewley, R. H., Crutchley, S., Shell, C. A. 2005. New light on an ancient landscape: lidar survey in the Stonehenge World Heritage Site, *Antiquity*, 79, 305 : 636–647

Bowden, M., 1999. Unraveling the Landscape: Inquisitive Approach to Archaeology, NPI Media Group, London

Boyda, D. S., Hillb, R.A. 2007. Validation of airborne LiDAR intensity values from a forested landscape using hymap data: preliminary analyses, *IAPRS,* XXXVI, Part 3 / W52

Corns, A., Shaw, R. 2004, ‘Archaeological Survey: A Review of 3D Data Capture Techniques’, In *Proceedings of the International Conference on Computer Applications and Quantitative Methods in Archaeology,* CAA 2004, 13-17 April, 2004, Prato, Italy

Doneus, M., Briese, C. 2006a. Digital terrain modeling for archaeological interpretation within forested areas using full-waveform laserscanning. In: M. Ioannides, D. Arnold, F. Niccolucci and K. Mania (Editors), *The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST* (2006), pp. 155-162.

Doneus, M., Briese, C., 2006b. Full-waveform airborne laser scanning as a tool for archaeological reconnaissance. In: S. Campana and M. Forte (Editors), *From Space to Place. Proceedings of the 2nd International Conference on Remote Sensing in Archaeology*. BAR International Series, 1568. Archaeopress, Rom, pp. 99-106.

Fenwick, J.. Newman, C. 2002. Geomagnetic survey on the Hill of Tara, Co. Meath. - 1998/99. *Discovery Programme Reports 6*, Royal Irish Academy, Dublin, pp. 1-18

Loisios, D., Tzelepis, N., Nakos, B. 2007. A methodology for creating Analytical hill-shading by combining different lighting directions, *Proceedings of 23rd International Cartographic Conference*, Moscow, August 2007.

Newnam, C. 1998. Tara: an archaeological survey. *Discovery Programme Monographs 2*. Royal Irish Academy, Dublin

Ancient and modern: Combining different remote sensing techniques to interpret historic landscapes

S. Crutchley

English Heritage, N.M.R.C., Kemble Drive, Swindon SN2 2GZ, UK, simon.crutchley@english-heritage.org.uk

Keywords: landscape, lidar, archaeology, interpretation, aerial photograph

ABSTRACT.

The Aerial Survey & Investigation team of English Heritage have been looking at the use of lidar data for the recording and interpretation of archaeological features in the landscape for a number of years. The team have substantial experience of working with aerial photographs and since 1990 have run a program of systematic interpretation and mapping known as the National Mapping Programme (NMP) that has now mapped over a third of England. The most recent project to make use of lidar data is covering the area of Savernake Forest near Marlborough in southern England. With its ability to "see through the trees", lidar has been shown to have particular benefit when working in a wooded environment and this was seen as an excellent opportunity to assess the advantages of this relatively new technique. The project area was mapped using both lidar and standard aerial photography and the results compared. As expected the lidar revealed a lot of features not previously recorded within the forest, but systematic and careful analysis of all the aerial photographs showed that a number of features "discovered" by lidar had in fact been visible on photographs for twenty, thirty and in some cases over seventy years! Furthermore because the forest had been an important military site during the Second World War there were features visible on the wartime photographs that have left no physical trace and were hence not picked up from the lidar, but which help to explain surviving features and are vital to understanding the full history of the area. The survey showed that whilst various techniques will reveal certain features, to get a full understanding of a landscape you need to take advantage of as wide a combination of sources and techniques as possible. Lidar data alone cannot provide all the necessary information to understand the historic landscape, but when it is combined with more traditional techniques, as at Savernake, it can prove a very valuable tool.

1 BACKGROUND AND CONTEXT

Airborne Laser Scanning (ALS) or Light Detection and Ranging (Lidar) had been in use in the commercial domain for many years before it came to the notice of archaeologists early in this century. It was not that archaeologists had not understood the potential of such a technique; it was simply that they were largely unaware it even existed. This changed in the UK when collaboration between the United Kingdom's Environment Agency and English Heritage showed that lidar was capable of picking up traces of features that were apparently not readily recoverable by the usual archaeological survey techniques (Holden *et al.*, 2001).

Since that time English Heritage have run a number of projects using lidar (Bewley *et al.*, 2005, Crutchley, 2006, Crutchley, 2008), especially working with the Unit for Landscape Modelling (ULM) at Cambridge University, who have carried out a lot of important research on the use of lidar in wooded landscapes (Devereux *et al.*, 2005; 2008). The technique has also been taken up elsewhere in Europe, again largely for use in woodland (Doneus & Briese, 2006; Shell & Roughley, 2004; Sittler, 2004). Whilst lidar has proved useful at recording any type of extant earthwork feature, even those that appear on the surface to have been completely eroded by ploughing or other activity (Bewley *et al.*, 2005) one of the particular qualities of lidar has been seen in its ability to "see through trees". This is a somewhat misleading statement that can lead to disappointment if the properties of lidar are not properly understood; the key element of lidar is light and as such it cannot see through trees or anything else. However, in some circumstances it can usefully be used to record the ground surface under a canopy of trees, something that has been exploited successfully by a number of researchers (Sittler, 2004; Doneus & Briese, 2006). However, lidar is not a magic bullet and will not record all the archaeological features that may be present. Most importantly, because it records differences in height the features being surveyed must have a 3D surface aspect; lidar does not penetrate the ground, so if the archaeological features of interest are not represented on the ground surface then lidar will not be able to record them. Secondly lidar is a "point in time" record, a snapshot of the ground at a particular moment and as such does not have the breadth of a conventional air photographic survey that looks at a wide range of photographs taken over a number of years, such as those carried out under the aegis of the National Mapping Programme (NMP) in England (Bewley, 2002).

2 SAVERNAKE FOREST NMP

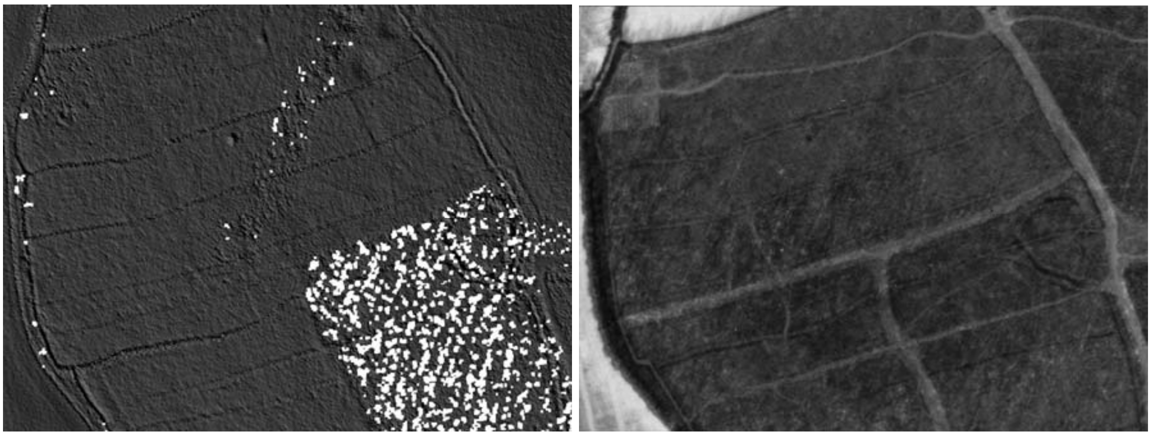
2.1 *Project methodology*

The most recent NMP project to use lidar has been looking at the area of Savernake Forest, near the town of Marlborough in the south-west of England. The project came about as an opportunity to test the capability of lidar for canopy penetration in an area of known archaeological potential. Savernake Forest is one of the most ancient woodlands in England, believed to be well over 1000 years old with the first known reference occurring in a charter of 993 AD (Dugdale 1693). It lies in an area of dense archaeology and stands out as a "blank spot" in a landscape otherwise densely populated by monuments of all ages. The project covered an area of 54 sq km of which approximately 19 sq km was covered by mature woodland. With the exception of finds of individual artefact there were less than a dozen archaeological features recorded within the main wooded areas of Savernake on the National Monuments Record (the national database of all archaeological remains in England), and these included the course of two major Roman Roads and the parkland associated with Tottenham House. Otherwise, the Forest appeared to be devoid of archaeological interest, in spite of the fact that just to the north lay the Roman settlement of *Cunetio* and the possible preceding Iron Age complex at Forest Hill.

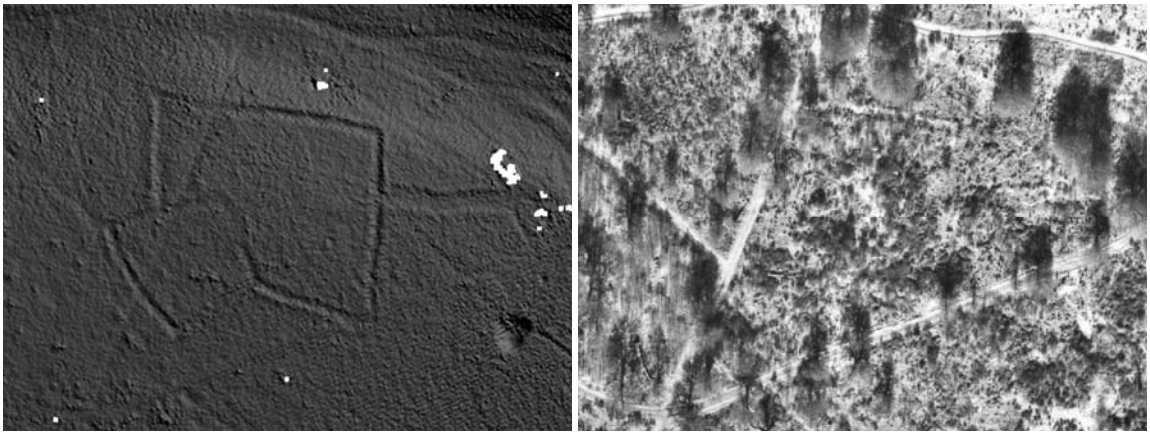
The survey was carried out using standard NMP methodology which requires interpretation of all readily available aerial photography in particular the extensive collections of historic vertical photography and specialist oblique photography held in the National Monuments Record; the Savernake project additionally looked at the lidar data as a separate source. Because part of the aim of the project was to assess how much data was provided by lidar as opposed to conventional photography, mapping and recording was conducted separately for each source. This meant that it was possible to analyse how many features had been recorded from the lidar data, how many from aerial photographs and how many from both.

2.2 *Methodological results*

When the lidar datasets had first been examined by staff from the Forestry Commission they had noted a large number of features that had not previously been recorded by either the NMR or the local Historic Environment Record (HER) and it was assumed that these were only visible because of the capability of lidar to penetrate the woodland canopy. In fact, close examination of the standard aerial photographs taken over a number of years revealed that a significant number of features were visible and would have been recorded previously had the photographs been examined in a systematic manner such as is undertaken during NMP. Two examples will suffice to confirm this; a probable late prehistoric settlement enclosure in Hen's Wood and an Iron Age enclosure that was previously known in part, put had been substantially revised by the lidar data.



Figures 1&2. A probable late prehistoric enclosure and field boundaries of medieval date in Savernake Forest. The previously unrecorded enclosure is visible middle right on both images and is arguably clearer on the conventional RAF photograph (right) than on the lidar derived imagery (left).Lidar image copyright English Heritage 2008; data copyright Forestry Commission - Source Cambridge University ULM (May 2006); aerial photograph RAF 540/958 4175 01-DEC-1952 English Heritage (NMR) RAF Photograph.



Figures 3&4. A late Iron Age enclosure in Savernake Forest. The southern edge of the enclosure had previously been recorded on the ground, but its complexity had not been realised until analysis of the lidar data. Examination of a range of aerial photographs from 1944 to 1970 revealed that large sections of the north and eastern edges were visible. Lidar image copyright English Heritage 2008; data copyright Forestry Commission - Source Cambridge University ULM (May 2006); aerial photograph OS 69014 06 07-MAR-1969 © Crown copyright. NMR

2.3 *Archaeological results*

Whilst part of the aim of the project had been to assess the relative benefits of using lidar and conventional photography in a woodland environment another core aim had simply been to increase our knowledge of all the archaeological remains within the project area. As noted above, the forest was something of a blank area compared with the surrounding land so it was important to try to reveal what had been happening in the forest and how that fitted into the local context.

To describe the results in a roughly chronological order, the earliest newly recorded features were a series of earthwork enclosures, similar to that illustrated above. There were ten to fifteen enclosures recorded, all averaging about 100m across and all roughly "D" shaped or polygonal. The majority were previously entirely unknown and recorded from a mixture of lidar derived imagery and traditional aerial photographs. Although very few had any direct relationships with other datable features, their general form and appearance is consistent with their dating from the late prehistoric period i.e. from the late Bronze Age (c1200BC) to the Roman conquest (43AD).

From a slightly later date there are a number of Roman roads in the Forest heading towards the Roman town of *Cunetio*. These had previously been recorded in very short stretches as earthworks, but were mainly marked on maps as "course of" since it was known that the road went in this direction, but was not exactly clear where it lay on the ground. The combination of lidar data and a fresh examination of aerial photographs have not only revealed further large stretches of the roads as extant earthworks, but have also led to a new understanding of the alignment of the roads as they approach Cunetio.

As is often the case with aerial surveys in England, there are no clear examples of features from early medieval times (c410AD – 1066AD), but there have been numerous records created relating to the medieval (1066 – 1540AD) and early post-medieval (1540 – 1901) periods. Amongst the most interesting records from medieval and post medieval periods are a series of pits marking the early parish boundaries and numerous examples of tracks and hollow ways that form the previous course of two of the major roads in the area.

The final period of interest in the forest takes us up to modern times when it was used as an ammunition depot both during, and immediately after, World War II. Although much was known about its use as a depot from documentary and oral history research (Day 2007) there had been no previous attempt to record the various structures related to its use. Using primarily a set of excellent photographs taken by the United States Army Air Force (USAAF) in March 1944 when much of the forest still had little leaf cover it was possible to record the precise location of hundreds of storage bunkers laid out predominantly along the line of the main avenues and tracks, presumably for easy access. The bulk of these had been constructed from corrugated iron and had consequently left virtually no trace on the ground; certainly nothing was visible on the lidar derived imagery.

3 CONCLUSION

The results of the project are threefold. Firstly, the survey has filled in a previous “blank spot” in the known archaeology of the area and has provided important information to the local and national records. This new information will help to ensure those managing the woodland in the Forest are able to make informed decisions that take into the account the heritage aspects of the landscape. Secondly, the project has confirmed the benefits of using lidar for recording and interpreting archaeological features in woodland; a number of features have been recorded that were previously unknown and would not have been discovered without this technology. Finally, it has shown that whilst lidar is a very useful tool that can often retrieve data that is not easily recoverable in any other way, it is not a panacea and is most effective for recording features in a multi-period landscape when combined with more traditional methods such as conventional aerial photography.

4 REFERENCES

Bewley, R.H. 2002. Aerial Survey: Learning from a Hundred Years of Experience? In Bewley, R.H. & Rączkowski, W. (Eds.) *Aerial Archaeology - Developing Future Practice’ Proceedings of the NATO Advanced Research Workshop on Aerial Archaeology, 15-17 November 2000.* NATO Life Sciences, Series 337: 11-18.

Bewley, R.H., Crutchley, S.P. & Shell, C. 2005. New light on an ancient landscape: lidar survey in the Stonehenge World Heritage Site. *Antiquity* 79, No. 305: 636-647.

Crutchley, S.P. 2006. Lidar in the Witham Valley, Lincolnshire: An assessment of new remote sensing techniques. *Archaeological Prospection* 13: 251-257.

Crutchley, S.P. In press. Using lidar in archaeological contexts: The English Heritage experience and lessons learned. In Heritage, G., Large, A. & Charlton, M. (Eds.) *Laser Scanning for the Environmental Sciences*. Oxford, Wiley-Blackwell.

Day, R. 2007. *Savernake at War*, Hungerford, Roger Day.

Devereux, B.J., Amable, G.S., Crow, P., Cliff, A.D. 2005. The potential of airborne lidar for the detection of archaeological features under woodland canopies. *Antiquity* 79, No. 305: 648-660.

Devereux, B.J., Amable, G.S. & Crow, P. 2008. Visualisation of LiDAR terrain models for archaeological feature detection. *Antiquity* 82, No. 316: 470-479.

Doneus, M. & Briese, C. 2006. Full-waveform airborne laser scanning as a tool for archaeological reconnaissance, In Campana, S. & Forte, M. (Eds.) *From Space to Place: 2nd International Conference on Remote Sensing in Archaeology*, BAR International Series 1568; 99 -105.

Dugdale, W. 1693. *Monasticon anglicanum, or the history of the ancient abbies, and other monasteries, hospitals, cathedral and collegiate churches, in England and Wales. With divers French, Irish, and Scotch monasteries formerly relating to England (Abridged),* London, 320.

Holden, N., Horne, P. & Bewley, R. 2002. High-resolution digital airborne mapping and archaeology. In Bewley, R.H. & Rączkowski, W. (Eds.) *Aerial Archaeology - Developing Future Practice’ Proceedings of the NATO Advanced Research Workshop on Aerial Archaeology, 15-17 November 2000.* NATO Life Sciences, Series 337; 173 - 175.

Shell, C.A. & Roughley, C.F. 2004. Exploring the Loughcrew Landscape: a New Approach with Airborne Lidar. *Archaeology Ireland* 18, no.2, Issue no. 68: 20-23.

Sittler, B. 2004. Revealing historical landscapes by using airborne laser scanning. In Thies, M., Koch, B., Spiecker, H. & Weinacker, H. (Eds.) *Laser-Scanners for Forest and Landscape Assessment: Proceedings of the ISPRS Working Group VIII/2*, Volume XXXVI, Part 8/W2,); 258-261.

Hyperspectral and LIDAR data fusion applied to archaeological studies: the Aquileia site

P. Sterzai[1], F. Coren[1], N. Creati[1], M. Vellico[1], C. Pietrapertosa[2]

1 Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Borgo Grotta Gigante, 42/c 34010 Sgonico (TS),e-mail: psterzai@iogs.trieste.it, fcoren@ogs.trieste.it, ncreati@ogs.trieste.it, mvellico@ogs.trieste.it

2 Istituto di Metodologie per l'Analisi Ambientale, Consiglio Nazionale delle ricerche,85050 Tito Scalo, Potenza, Italy, tel: +39 0971 427111, fax: +39 0971 427271, e-mail: pietrapertosa@imaa.cnr.it

Keywords: Hyperspectral images, Lidar , archaeological site

ABSTRACT.

Data acquired by Lidar and hyperspectral systems can help identify old buried archaeological structures. These technologies are able to measure some markers that depend on the change of the radiometry and dimensions of the earth surface. The markers can trace bedrivers, environmental, archaeological and anthropic structures. Even if both Lidar and hyperspectral are based on different methodologies they can be a powerful way to detect some markers, since data and information achieved by both systems are strictly related.

A survey over the area of Aquileia, settled in North-Eastern Italy, allowed the recognition of some buried features, such as town-walls, roads, buildings and an ancient riverbed of Roman age. The city of Aquileia is one of the most famous archaeological site in Northern Italy and has been erected on 181 B.C.. Aquileia was an important commercial town of the Roman empire and its river harbour was one of the biggest in Italy. The city was characterized by an elongate shape, several town-walls, four square districts and perpendicular streets according to the cardinal points.

Hyperspectral data have been acquired by an AISA Eagle system using a spectral range between 400 and 1000 nm. A classic principal component analysis on the hyperspectral data pointed out the presence of some archaeological features: a kiln, some roads, some buildings walls and the trace of an ancient bedriver. A classification with a clustering method confirmed the occurrence of the structures already recognized.

Lidar data had a density of one point for square meter and a simple DEM clearly showed features that matched the archaeological map of the city. Shaded relief maps of the area pointed out the city town-walls and the kiln. Lidar data has the advantage to recognize small elevation changes that are usually associated to buried structures. The information retrieved by the Lidar analysis have been used to verify the results of the hyperspectral analysis.

The joint interpretation of Lidar and hyperspectral data has let us suppose the location of an ancient kiln, the town-walls, some buildings footprint, an old riverbed with its wharfs.

There are still some open questions regarding the spectral signatures of the land as a function of the buried building materials and atrophic debris content. An archaeological diggings survey would be useful to check some of the conclusions outlined with this work and the efficiency of remote sensing methods in archaeological studies.

1 INTRODUCTION

The aim of this work is the joint use of hyperspectral and Lidar data to provide archaeologists with information about old buried archaeological structures. The hyperspectral data give information about environmental markers, as ground composition, soil moisture and vegetation coverage. The Lidar data provide high spatial resolution data and their intensity can help depict important ground features, after a calibration phase. This integrated information provide indications about the location and the geomorphic structure of the Aquileia site. This study is the carrying on of a previous work written by Coren et al.(2005), and extends the elaboration processing on the data acquired by hyperspectral Aisa Eagle sensor.

2 LIDAR DATA

Airborne Lidar (Light Detection and Ranging) furnish high-accuracy spatial information; these results are essential to describe the geometry of the territory. Airborne Lidar scans the surface by emitting a high frequency laser pulse in the Infrared field. The average point density value of datasets varies between 1 and 10 points/m2. The accuracy you can obtain with Lidar is 30 cm in xy and 10 cm in z. The final products are high resolution Digital Surface Models (DSM) and Digital Terrain Models (DTM). By applying some appropriate numerical filters on Lidar data it is possible to highlight existing micro variations in elevation on the terrain and to separate the terrain from vegetation, building, infrastructures etc.; this process is called *classification* and is fundamental for archaeological applications, because it allows the discovering of ruins under the ground.

3 HYPERSPECTRAL DATA

The analysis of the spectral signature permits to identify different materials. Actually some hyperspectral sensors are available, with high spatial resolution, a great number of bands and a minimum wavelength; these characteristics allow to identify accurately the target. It is possible to combine different bands (ratio, difference..) to obtain different indexes that describe chemical and physical characteristics; they are influenced by the presence of buried structures. These produce a humidity variation (Emmolo, 2004) and a higher terrain consolidation, also visible as a chromatic variation. In the present study, the interactions of buried structures with surface characteristics are examined by principal component analysis to identify features in the data, their similarities and differences; by classification process, pixels belonging to the same classes are identified, in particularly to detect the buried features class.

3.1 *Principal component analysis*

The principal component analysis (PCA) is a method useful to reduce data dimensionality, but also to help recognize different features (Lasaponara & Masini, 2007). A new set of orthogonal axes is considered, having their origin at the data mean and being rotated, so that data variance is maximized. Every output band is a linear combination of the original spectral band and is uncorrelated. The first PC band contains the largest percentage of data variance and the second PC band contains the second largest data percentage, and so on. The last PC bands appear noisy because they contain very little variance, much of which is due to noise in the original spectral data. Principal component analysis is calculated using mathematical and statistical concepts as: standard deviation, covariance, eigenvectors and linear transformations. Considering a p-dimensional random vector **X** = $\lfloor x_1 x_2 \ldots x_p \rfloor^T$, it is possible to obtain a new vector represented as **Y**, a linear transformation of the original co-ordinates, **Y**=**LX**

a generic component of vector **Y** is:

$$Y_1 = (Y_{11}, Y_{12}, \ldots, Y_{1P}) = (\sum_{i=1}^{p} l_{1i} X_{i1}, \sum_{i=1}^{p} l_{1i} X_{i2}, \ldots, \sum_{i=1}^{p} l_{1i} X_{ip}) \qquad (1)$$

where the coefficient vector $l_1, l_2, \ldots, l_p$ are chosen according the following conditions:

j-th principal component : $l_j X$ that maximizes Var(l_j ,**X**) and $\|l_j\| = 1$;
Cov(l_i**X**,l_j**X**)=0 i<j.

4 CASE STUDY

The study area is the city of Aquileia, located in North-Eastern Italy. The city was erected on 181 B.C.. Aquileia was an important commercial town of the Roman empire and its river harbour was one of the biggest in Italy. In Aquileia a great number of ruins exists, some of them have been found and restored in situ, but the most part of them is still buried. Airborne Lidar and hyperspectral data were acquired simultaneously during a survey on the Aquileia city in April 2005, with a flight height average of 1000 m. Lidar data were collected by an Optech ALTM 3033 system, hyperspectral data by the Airborne Imaging

Spectrometer (Aisa-Eagle system), both mounted on a helicopter.

4.1 *Optech ALTM 3033 dataset*

The Lidar Optech ALTM 3033 sensor works with a NdYAG laser (1064 nm), with an average power of 6.5 W and a frequency of 33 hKz. The dataset point density is 1 point/m^2. It is able to record two different echoes per pulse emitted, and the relative intensity reflection information.

4.2 *Aisa Eagle dataset*

The Aisa Eagle system, is developed by Spectral Imaging Ltd (Specim, Finland); it is a pushbroom system up to 1000 pixels swath width in the spectral range from 400 to 1000 nm. It consists of a hyperspectral sensor head, a data acquisition unit in a PC, a GPS receiver and an inertial navigation system. The Aisa configuration for the Aquileia flight was settled on 63 bands in the whole spectral range, the average band interval was 9 nm, the ground pixel size was 1 m. The dataset was pre-processed according to three phases. *Radiometric correction*: the acquired raw digital numbers were transformed into radiometric values (radiance) by caligeo software, using the sensor calibration file. *Geocoding*: the image was geometrically corrected and georeferred, by PARGE (Schläpfer et al., 2002). *Atmospheric correction*: it was applied in order to remove the atmospheric effects and to produce the at-surface reflectance, using a radiative transfer model by ATCOR-4 software (Ritcher et al., 2002). The atmospheric corrections implemented in ATCOR-4 are based on a large "monochromatic" database of atmospheric correction functions compiled with the MODTRAN-4 code.

4.3 *Analysis*

A simple visual interpretation of image data permits the identification of features based on the different colour, tone and texture within the image. The data are represented using a mixed colour of the three primary colours (Red, Green, Blue - RGB), every single band being represented as a layer of one of RGB colours. Three features are clearly visible in this primary interpretation (see figure 1): a) the external enclosure walls of the ancient city already classified by Soprintendenza Archeologica del Friuli Venezia Giulia, b) the unknown polygonal feature, c) the course of paleo river and its ramifications.

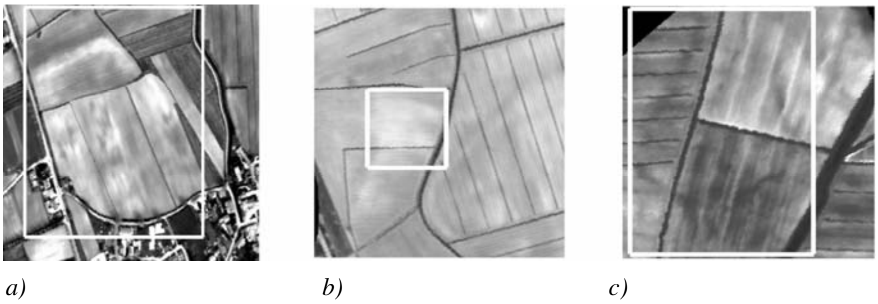

a) b) c)

Figure 1 a) external enclosure walls, b) the unknown polygonal form, c) paleo river and its ramification.

Analyzing the correlation matrix, the bands result highly correlate, therefore the PCA (Principal Component Analysis) technique was used to produce uncorrelated output bands, in order to recognize features not easily detectable on the ground. The PCA used, implemented on ENVI (RSI), was calculated on all the spectral bands registered, masking the background not to influence the calculated algorithm. The result of PCA shows marked features in the first and the second principal component bands (respectively pca1 and pca2); these features match with those recognize by the visual inspection. In figure 2 we show the results of the PCA analysis; the buried structures are characterized by brighter grey tones in pca1 and by darker colours in pca2.

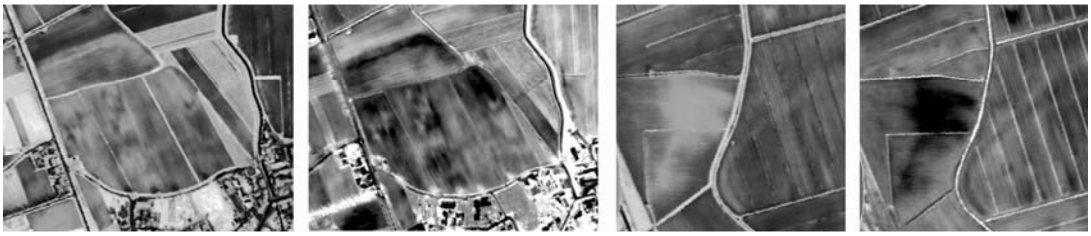

a) b) c) d)

Figure 2 external enclosure walls: a) pca1, b) pca2 - the unknown polygonal form: c) pca , d) pca2.

4.4 *Classification processing*

An unsupervised classification was applied using the Iterative Self Organized data Analysis technique A method (ISODATA) (ref. ENVI, ITT). The algorithm is iterative, it begins with arbitrary cluster means evenly distributed in the data space. Each iteration recalculates the means and reclassifies pixels with respect to new means using the minimum distance technique. This process continues until the number of pixels in each class changes by less than the selected threshold or the maximum number of iterations is reached. The ISODATA algorithm was applied to a selected subset of images, containing the ancient walls already known, in order to recognize structures belonging to the same class. Different parameters sets were used to perform the ISODATA analysis. Figures 3 and 4 show the classification results setting different parameters; it is clear that, even if fixing a configuration parameter data set, buried structures are recognised in the same class. The difference among the three configurations is the different number of classes that characterize the structure.

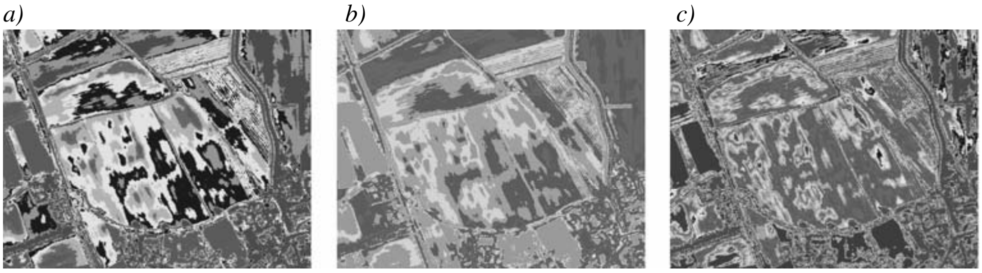


Figure 3 external enclosure walls a) class #=7, b) class #=12, c) class #=17.

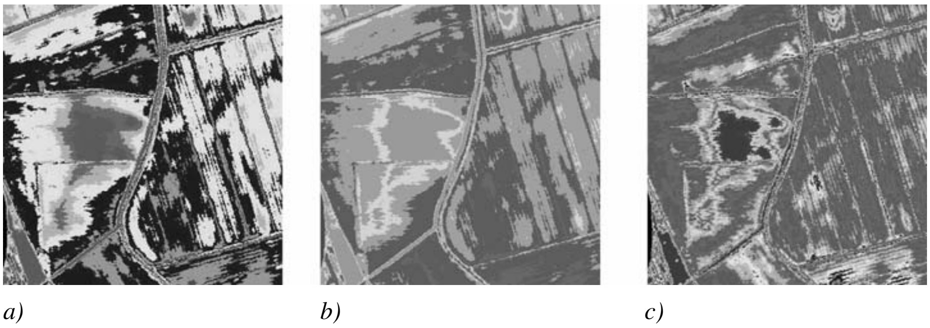
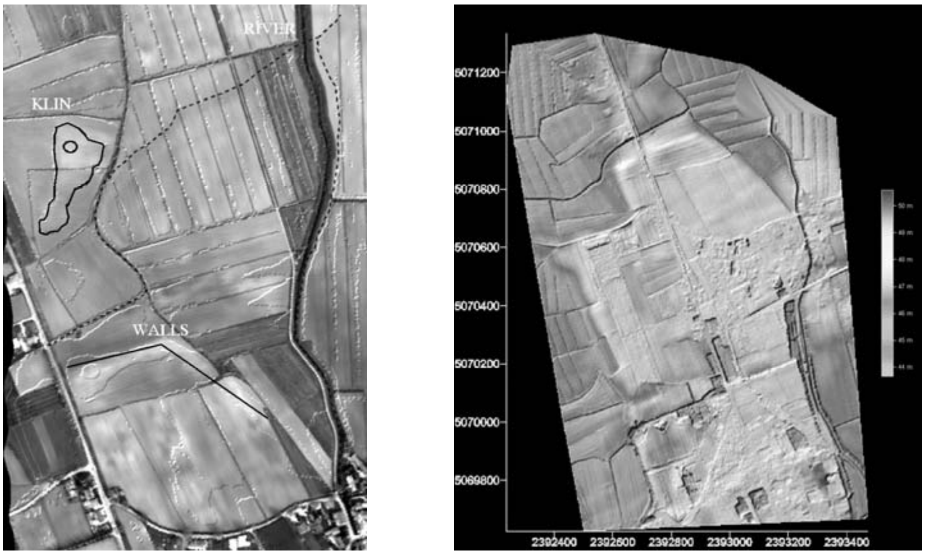


Figure 4 site of probable archeological interest a) class #=7, b) class #=12, c) class #=17.

Supervised classification was carried out on images using Spectral Angle Mapper (SAM) implemented on ENVI. This classification compares known spectra (spectral libraries or endmembers) with spectral image. The results are the classified image and the optional rule images that show the smaller angles that match to the reference spectrum. In the Aquileia study 8 regions of interest were recognized, among them the class of external walls, with a spectral angle threshold of 0.1 radians. The result image didn't supply information about the buried ruins, it showed a correct classification validated on the site; analyzing the rule image of the defined roofs class, the darkest pixels indicating a more similar spectral signature to the selected class were in correspondence of ancient walls and unknown buried structure.

4.5 *Lidar data interpretation*

The Lidar DTM analysis revealed some buried structures in the same position emerging from the hyperspectral results (see figure 5). The clearest features are the ancient enclosure walls that border some buildings and perpendicular roads. The unknown polygonal feature revealed itself as a probable kiln, according to its shape and historical structural elements, after a shaded relief maps analysis. DTM was realised applying a Gaussian low pass filter to the Lidar dataset and multiplying z values by an appropriate factor, so to highlight elevation discontinuities (Coren *et al.*, 2005). DTM is a powerful instrument to detect buried features and to validate hyperspectral classification results, since evidences the micro-variations in the terrain. The buried features were also highlighted by conducting an intensity reflectance analysis of Lidar data (Coren & Sterzai, 2006); calibrated data were characterized by strong differences between buried features and the ground surrounding.



a) *b)*

Figure 5. a) Interpreted hyperspectral image superimposed to DTM b) DTM displayed by elevation.

5 CONCLUSIONS AND FUTURE OUTCOME

In this paper we suggest a method that help recognize existing anomalies in the ground, starting from hyperspectral data, validated by small digital terrain model discontinuities. Hyperspectral data classification and analysis allow the identification of some new buried structures, using radiometric properties. PCA and ISODATA reveal themselves as valid methodology to locate and delineate probable new archaeological finds. Lidar data, supplying also the intensity information, are necessary to accurately detect the geometry of buried structures in order to primarily classify features and to properly direct archaeologists in excavations. There are still some open questions regarding the spectral signatures of the land as a function of the buried building materials; in the future they could be validated by the comparison with some ground field measurements.

REFERENCES

Coren, F., Sterzai, P. 2006. Radiometric correction in laser scanning. *International Journal of Remote Sensing*, 27:3097-3104.

Coren, F., Visintini, D., Prearo, G., Sterzai, P. 2005, Integrating LIDAR intensity measures and hyperspectral data for extracting of cultural heritage, *Workshop Italy-Canada 2005*, Padova 17-18 maggio 2005.

Emmolo D., Franco V., Lo Brutto M., Orlando P., Villa B. 2004. Hyperspectral techniques and GIS for archaeological investigation, *IAPRS&SIS, Istanbul, XXXV, B7*, 492-497.

Lasapanora, R., Masini, N. 2007, Improving satellite Quickbird – based identification of landscape archaeological features trough tasselled cup transformation PCA, *21st CIPA Symposium, Atene, 1-6 giugno 2007.*

Richter, R., Schläpfer, D. 2002, Geo-atmospheric processing of airborne imaging spectrometry data. Part 2: Atmospheric/Topographic Correction. *International Journal of Remote Sensing*, 23(13):2631-2649.

Schläpfer, D., Richter, R. 2002, Geo-atmospheric Processing of Airborne Imaging Spectrometry Data Part 1: Parametric Orthorectification. *International Journal of Remote Sensing*, 23(13) : 2609-2630.

GIS based processing of multiple source prospection data in landscape archaeology

S. Boos[1], H. Müller[1], S. Hornung[2], P. Jung[2]

1 Mainz University of Applied Sciences, ,Institute for Spatial Information and Surveying Technology (i3mainz), D-55116 Mainz, Holzstr. 36, Germany,E-mail boos@geoinform.fh-mainz.de, mueller@geoinform.fh-mainz.de
2 Mainz University, Institute for Pre- and Protohistory, D-55116 Mainz, Schillerstr. 11,Germany, Email: hornusa@uni-mainz.de, patjung@uni-mainz.de

Keywords: Airborne Laser Scanning, Terrestrial Laser Scanning, Sub-surface Geomagnetic Prospection, GIS, Digital Elevation Model, Topographical Survey

ABSTRACT:
In a project dealing with landscape archaeology the Institute for Pre- and Protohistory of Mainz University and the Institute for Spatial Information and Surveying Technology (i3mainz) of the University of Applied Sciences Mainz have been examining the area around the Celtic oppidum "Hunnenring" in the northern Saarland (Germany) since the end of 2006. Its wall is partly preserved up to a height of 10 m, which makes it one of the largest Celtic structures of its kind. Various sources indicate that the low mountain range, which is nowadays situated peripherally, used to be a significant centre with supra-regional importance in Celtic times. Aided by various archaeological prospection methods and the use of methods of applied geoinformatics and surveying technology it is attempted to reconstruct the pre- and protohistoric habitat as detailed as possible. A special focus is made on tracking early use of resources and on the question to what extent local iron and copper-ore deposits affected economic activities of people.
However in this project we used a combination of different archaeological prospection techniques and methods of modern 3D-surveying technology to achieve this aim. A conventional method to record anthropogenic characteristics of the relief is surveying with a total station. The recorded terrain points are used for creation and visualization of a Triangular Irregular Network (TIN) in a GIS. By this means very fine characteristics of the relief, like terraces of settlement, old routings and historical mine shafts can be documented. *Airborne Laser Scanner Data* were used for 3D modelling of the complete investigation area because of their potential to capture a dense cloud of terrain points in high quality, particularly in wooded areas, where good conservation of archaeological structures is indicated. For selected regions a *Terrestrial Laser Scanner* was used to generate a *Digital Elevation Model* (DEM) of even higher resolution. A conventional archaeological prospection technique is the surveying of single finds. For this purpose a ploughed acre was paced off systematically and the positions of single finds were recorded by using *total station and GPS*. Particularly for detection of sub-surface metalliferous materials the use of *geomagnetic prospection* is a very helpful method. Recording and analysis of anomalies of the earth magnetic field yields a method to detect ditches, pits and other filled-in intrusions of the ground, but also high temperature areas e.g. caused by smelting. The surveying of such anomalies was executed by capturing data along a regular pattern in the field. The measuring values were recorded in a dense interval in a decimetre range. The values of anomaly measurement were represented as gray scale values.
The results of all measurements were integrated for visualization in a GIS and applied for further analysis. High-resolution DEM, which have been generated using Airborne-Laserscanning (ALS) data, are a core component. The information, that was generated using various methods such as geophysics, surveying of single finds, ALS and excavations, in combination with significant factors such as soil quality, geology, waterlogging, slope and water proximity, can be included well in analysis of settlement history.

1 INTRODUCTION

The reconstruction of a pre- and protohistoric habitat with its network of human settlements, sacred places, cultivation- and field areas and natural resources is referred to as landscape archaeology. For work on a landscape scale rather than excavating particular sites, a new methodology has to be established (Campana & Francovich, 2003). Hence research here relies on special prospection techniques like surveying of single finds, geophysical prospection and aerial archaeology, which all aim at retrieving historical sites without disrupting their archaeological context.

In recent times landscape archaeological research increasingly uses methods and technologies of photogrammetry and geoinformatics for approximation of the prehistoric habitat. In particular Airborne Laserscanning (ALS) is applied in archaeology to produce detailed relief maps of archaeological sites (Challis, 2006; Sittler, 2004). High resolution Digital Elevation Models (DEMs), which can be generated from ALS-data, enable a detailed representation of the earth's surface. In particular wooded areas, which can only be prospected very laboriously and even aerial archaeology is of limited use here, reveal the excellent prospects of using ALS data for archaeological purposes (Kraus & Pfeifer, 1998; Devereux *et al*., 2005). Still in woodlands even the accuracy of ALS-Data is sometimes insufficient, but at least smaller areas containing archaeologically interesting structures can be detected by use of Terrestrial Laser Scanning (TLS). A Geographic Information System (GIS) provides for good capabilities to visualize and combine the information gained by different methods. As an analytical tool GIS helps to identify indications for further prospection activities.

2 AREA OF STUDY

The Celtic oppidum "Hunnenring" with its fortified walls preserved up to a height of 10 m is situated on the ridge of the Dollberg Mountain (figure 1) in northern Saarland (Germany). The large amount of human resources needed for construction of these fortifications indicates that this Celtic town from the 2nd and 1st century BC used to be a significant centre of supraregional importance and also a home to the local elite. Whereas for the second and first century BC the Dollberg plateau served as a central settlement for a major community, other finds from the immediate vicinity indicate that settlement activities continued throughout the following Roman period as well (Wiegert, 2002).

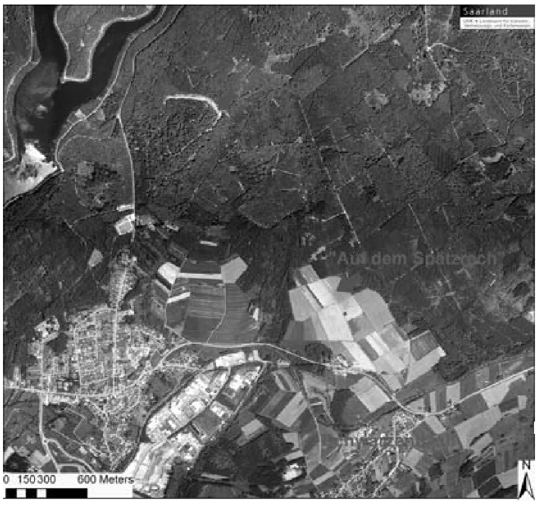


Fig.1: The Area of Study

From an archaeological point of view one important focus of interest lies on the question which economic factors influenced the Celtic-Roman settlement in this nowadays peripherically situated region. Until mid 19th century the region around the "Hunnenring" was an important centre for mining on local copper and iron-ores, resources that may also have been an important economic basis in Celtic and Roman times. Hence the intention of landscape archaeological research in this area is to find proof of prehistoric mining activities for iron and copper ore. To achieve this aim, selective prospection of archaeological sites in the region is conducted.

In 2007 prospection work concentrated on an area of appr. 20 ha, which is situated 1.2 km southeast of the "Hunnenring" close to the village Schwarzenbach (figure 1). In this area a Gallo-Roman temple was excavated in the 1980s and only recently the remains of a civil settlement (vicus) in the vicinity were unearthed, located on the nowadays agriculturally used subdistrict "Auf dem Spaetzrech" (Miron 2000). The site is surrounded by protected spruce plantation areas and mixed forest. Towards the northeast the wooded Muenzbach valley represents a distinctive score in the terrain. Here our prospections aimed at gaining further knowledge about the expansion of the settlement.

3 METHODOLOGY AND RESULTS

A combination of different archaeological prospection techniques and methods of surveying technology was used to achieve this aim. The results were used for visualisation in a GIS and applied for further analysis. In the following sections the used methods of prospection and their results will be described and discussed.

3.1 *Laserscanning*

Recording anthropogenic structures by means of a total station is the conventional method used in archaeological prospection for documenting fine characteristics of the relief, like settlement-terraces, old routings and historical mine shafts. The recorded terrain points are used for the creation and visualization of a Triangular Irregular Network (TIN) in a GIS. In the recent past ALS-Data are used increasingly for these archaeological applications because of their potential to determine a dense point cloud (up to several points per m²) in high quality.

In our area of study some topographically interesting areas were explored in order to outline significant landscape-features. Especially the relief of the Muenzbach valley shows a multiplicity of significant anthropogenic changes like for example a recent stone pit, a footpath and some distinctive patterns of boulders. All this leads to the hypothesis of an ancient pathway connecting the “Hunnenring” to the nearby Roman settlement. In order to achieve a most homogeneous representation of the terrain with regard to detail DEM’s were generated by means of total station data, ALS data and TLS data.

The survey of the terrain by total station was accomplished by a total of 17000 points, with a point density of up to 4 points/m² in the Münzbach valley. In GIS ESRI ArcGIS a TIN was generated from the measured points. Also in ArcGIS a TIN was calculated from ALS data with an average point density of 1.5 points/m². The resulting DEMs show a clearly recognisable structure to the south of the Roman temple, which has the shape of a rampart (figure 2). During excavation in the 1980s this rampart was misinterpreted as being the border of the Roman settlement.

The area of the recent stone pit was surveyed by means of TLS. A 1 ha size area consisting of the recent stone pit and its surroundings was recorded with the Leica Laser Scanner HDS 3000 with a terrain point accuracy of 15 cm. The single scans were registered in the program *Leica* Cyclone and thinned out by a special software-development from the i3mainz and visualized as a TIN in ESRI ArcScene (figure 3). As a result a line structure, which slopes down into the river valley of the Muenzbach and which continues on the other side of the shore can be associated with the already mentioned patterns of boulders, suggesting a direct connection to the “Hunnenring”.

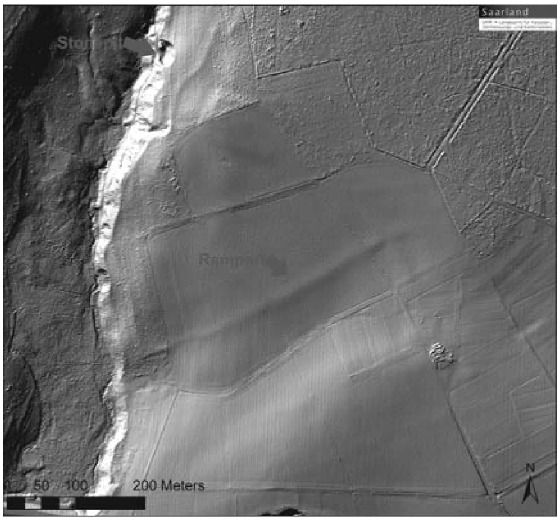


Fig. 2: Shaded DEM of the Area of Study

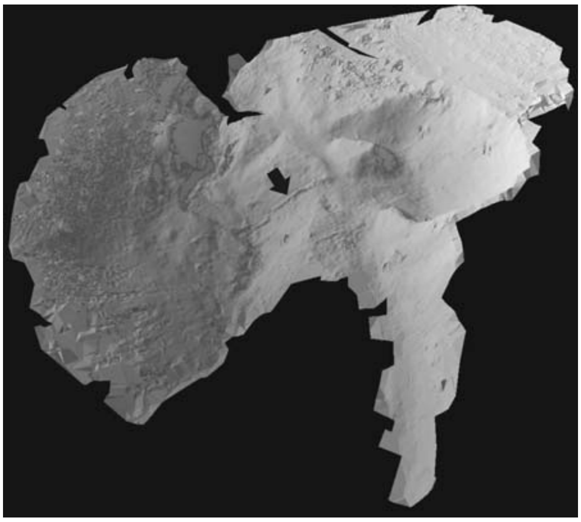


Fig. 3: The recent stone pit visualized in ArcScene

3.2 *Recording of single finds*

A conventional archaeological prospection technique is the surveying of single finds (Gillings, 2006). For this purpose a ploughed acre is paced off systematically and the positions of finds are recorded by using total station or GPS. However in woodlands only selective prospection is possible. In this case soil exposures of every kind are used: waysides, lanes of forest vehicles, river beds, root plates or other places without vegetation. Typical and common soil exposures on meadows are molehills. In order to interpret the disposition of archaeological finds in molehills the position of every single molehill has to be recorded. By this means a differentiation between areas with finds and areas without can be achieved.

In our area of study single finds were recorded in the centrally located agricultural cropland and the forests northwest of the temple. On wasteland and meadows about 273 molehills were prospected and investigated for finds. Approximately 1400 single finds were categorized and visualized in ArcGIS (figure 4). It turns out, that the major part of the finds consists of brick fragments, which concentrate clearly on an area south of the temple. Thus this area can be interpreted as the centre of the former settlement. Towards the south finds are thinning out with increasing distance. A major number of bricks was found in the forest northwest of the temple and in the Muenzbach valley. Therefore the allocation of the finds extend to an area larger than suspected before, indicating that the settlement had a greater expansion than previously assumed.

3.3 *Geomagnetic prospection*

Particularly for detection of metalliferous materials the use of geomagnetic prospection is a very helpful method. Geomagnetic prospection utilizes the property of the terrestrial magnetic field to induct every kind of material magnetism. The level of induction can differ considerably for geomagnetic sensitive materials like stone, metalliferous objects, pottery or high temperature areas (e.g. in sections of smelting) (Froehlich *et al.*, 2003).

The geomagnetic survey is executed by means of special instruments (Caesium-Magnetometer or Fluxgate-Gradiometer) and used to locate and delimite magnetic objects by capturing the anomalies along a regular pattern in the field. Measuring values are recorded in dense interval in a decimetre range and processed by using special software programs for geomagnetics or in stand alone image processing software. Here measuring values are represented in gray scale, particularly specified by requirement and estimation of a geophysicist.

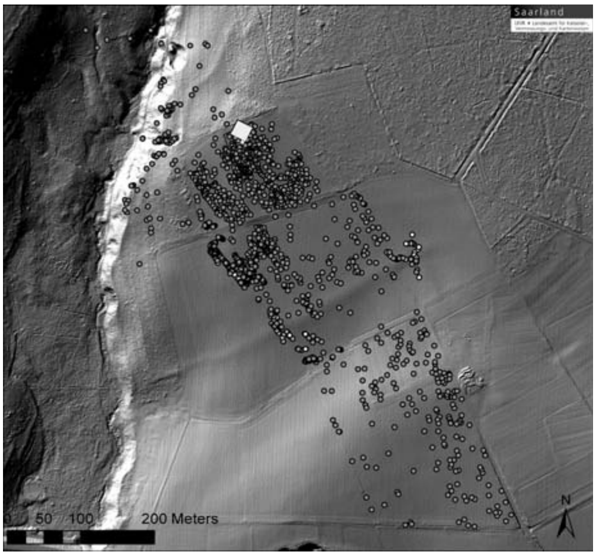


Fig. 4: Allocation of single finds on the Area of Study

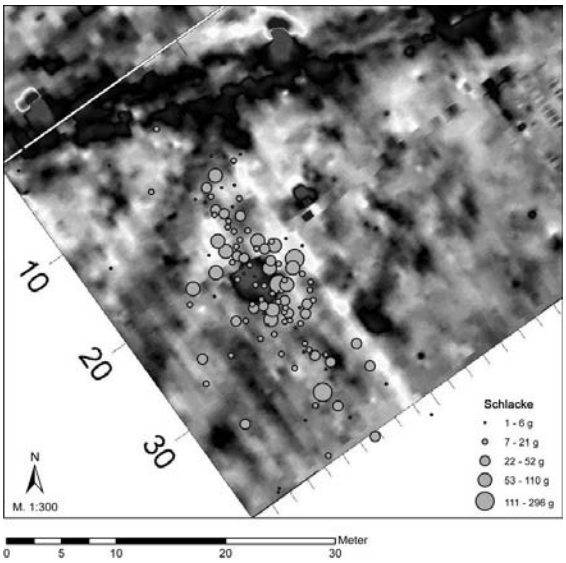


Fig. 5: Correlation between slag concentration and geomagnetic anomaly

On the Roman vicus-grounds the area adjacent to the south of the temple was prospected in a geomagnetic survey, the results of which were visualized in the program *Golden Software* Surfer. Two striking anomalies southwest of the temple can now be linked with metal-processing, since one of these anomalies was found to correlate with a peculiar high concentration of slags (figure 5). Excavation showed a roughly 40 cm strong, thick dark grey up to black layer filling in a sewage pit and primarily consisting of slags, Roman bricks and fragments of pottery.

4 CONCLUSIONS AND FUTURE WORK

Using various prospection methods of archaeology and surveying techniques knowledge of the Roman settlement “Auf dem Spaetzrech” was improved significantly. Different methods of topographical surface recording were used to produce detailed topographical maps of the study area. The resulting DEM’s proved to be of great help to sharpen the image of the historical landscape. The results of geomagnetic prospection and of the collection of single finds were visualized in a GIS. It was shown that those single finds are distributed over a wider area than suspected so far, which means that the Roman settlement covered a larger area than previously assumed. The geomagnetic image was combined in a GIS with the distribution of slags and proved a correlation between geomagnetic anomalies and a high concentration of slags. During excavation this anomaly provided evidence of antique metal processing. An area of about 1 ha size in the Muenzbach valley was scanned with a terrestrial laser scanner to get a much more detailed image of the topography than was obtained from the results of ALS and topographical recording. The resulting DEM showed a small structure, which possibly belongs to a pathway connecting the Roman settlement with the "Hunnenring". Processing of the TLS-data also showed that the use of a Terrestrial Laser Scanning TLS in wooded areas is a good alternative to ALS and conventional topographical recording.

Further research will concentrate primarily on the proof of mining, using ALS data as an important basis for archaeological prospection. In GIS important location criteria like spatial patterns of soil quality, geology, waterlogging, slope and water proximity will be managed and set in reference to the archaeological finds, in order to predict potential locations for further archaeological sites.

5 REFERENCES

Campana, S., Francovich, R. 2003. Landscape Archaeology in Tuscany: Cultural resource management, remotely sensed techniques, GIS based data integration and interpretation. *The Reconstruction of Archaeological Landscapes through Digital Technologies*, 15 – 28.

Challis, K., 2006. Airborne Laser Altimetry in Alluviated Landscapes. *Archaeological Prospection*, 13 (2), 103 – 127.

Devereux, B.J., Amable, G.S., Crow, P., Cliff, A.D., 2005. The potential of airborne lidar for detection of archaeological features under woodland canopies. *Antiquity,* 79, 648 – 660.

Doneus, M., Neubauer W., Studnicka, N. (2003): Digital Recording of Stratigraphic Excavations. *The CIPA Int. Archives for Documentation of Cultural Heritage*, Vol. XIX, 151 – 156.

Froehlich N., Posselt, M., Schleifer N. 2003. Excavating in "blind" mode. Magnetometer survey, excavation, and magnetic susceptibility measurements of a multiperiod site at Bad Homburg, Germany. *5th International Conference on Archaeological Prospection , Cracow, Poland. Arch. Polona 41*, 167-169.

Gillings, M. 2006: Ancient Landscape, Settlement Dynamics and Non-Destructive Archaeology. *European Journal of Archaeology 2005/ 8*, 190-193.

Kraus, K., Pfeifer, N. 1998. Determination of terrain models in wooded areas with airborne laser scanner data, *ISPRS Journal of Photogrammetry and Remote Sensing* 53 : 193 – 203.

Miron, A. 2000. Der Tempel von Schwarzenbach „Spätzrech“, Kr. St. Wendel. Zur Aufarbeitung eines Altfundkomplexes. In: A. Haffner/S. von Schnurbein (Hrsg.*), Kelten, Germanen, Römer im Mittelgebirgsraum zwischen Luxemburg und Thüringen [Koll. Trier 1998]. Koll. Vor- u. Frühgesch.* 5 (Bonn 2000) 397-407.

Sittler B. 2004. Revealing historical landscapes by using airborne laser scanning.Laser-Scanners for Forest and Landscape Assessment. *Proceedings of the ISPRS working group VIII/2 Volume XXXVI, Part 8/W2,* 258-261.

Wiegert, M. 2002. Der "Hunnenring" von Otzenhausen, Lkr. St. Wendel. Die Siedlungsfunde und Bebauungsstrukturen eine spaetlatenezeitlichen Hoehenbefestigung im Saarland. *Internat. Arch.*65. Rahden, 2002.

4

Sub-surface reconstruction based on GPR, magnetic and electrical tomography for archaeological research

The Role of Integrated Geophysical Survey Methods in the Assessment of Archaeological Landscapes: the case of Portus

K. Strutt[1], S. Keay[2]
1 APSS, Department of Archaeology, University of Southampton, Highfield, Southampton, SO17 1BF, UK, email: kds@soton.ac.uk
2 The British School at Rome, Via Gramsci 61, 00197, Rome, Italy
Department of Archaeology, University of Southampton, Highfield, Southampton, SO17 1BF, UK,
Email: S.J.Keay@soton.ac.uk

Keywords: Geophysical Survey; Landscape; Roman Ports; Integrated Methodologies

The regular application of geophysical, geochemical and topographical survey techniques to evaluate archaeological sites are well established as methods for locating, defining and mapping buried archaeological materials. However, it is not always feasible to apply a range of different methods over a particular site or landscape due to constraints in time or funding. This paper addresses the integrated application of a variety of survey techniques over different sites and landscapes in the Mediterranean and elsewhere, demonstrating the benefits in terms of the assessment of the archaeological resource. It does so by looking at the results from ongoing survey and excavations at Portus, the port of Imperial Rome.

An integration of methodologies, including magnetometry, resistivity, Ground Penetrating Radar and resistance tomography, can be used to highlight a number of different research objectives, ranging from geomorphological analysis, to recording of the nature and extent of urban centres, and variations in archaeological potential across entire landscapes. Using different software programs for processing of survey data, and merging different datasets using GIS packages, allows the results of such work to be visualized and presented to archaeologists in a comprehensive and unambiguous fashion, allowing decisions to be made about the future management and preservation of the sites and landscapes in question.

1 INTRODUCTION

The widespread application of geophysical and topographical survey techniques to archaeological sites in the mediterreanean is not a recent phenomenon. In particular recent approached to classical archaeological sites, and in particular urban centres, have demonstrated the benefits of geophysical survey applied over a broad area to establish the nature and extent of archaeological features (Hay *et al.*, 2006; Keay *et al.*, 2005; Keay *et al.*, 2006; Keay *et al.*, 2007).

Whilst survey over a large site or landscape, using one particular technique, is ultimately beneficial, and can completely alter our understanding of a study area (Keay *et al.*, 2005; Powlesland & Lyall, 1996) the result can have a degree of superficiality when presented as a single approach. The plan that is derived from a magnetometer or resistivity survey over an entire site presents the researcher with an accurate and high-resolution representation of archaeological and geomorphological features, and through intuitive interpretation using the morphology of different features the nature and development of the site or landscape can be understood. However the full nature, depth and relationship between areas of a site or different features from differing site phases are not always apparent. It is the integration of different methodologies and techniques that can furnish the researcher with a variety of datasets and give a more nuanced and complex representation of a site.

Use of electrical pseudosections (Aspinall & Crummett, 1997; Walker, 2000) or, for deeper stratified deposits, resistance tomography (Bates & Bates, 2000) facilitate our comprehension of archaeological deposits including structural elements and, when used in conjunction with borehole data, variations in sediment size and clast inclusions (Bunbury *et al.*, 2008). Systematic use of these methods allows three-dimensional mapping of a site or area to be produced (Papadoulos *et al.*, 2006).

In addition use of Ground Penetrating Radar (GPR) can be integrated either intuitively or quantatively with other datasets to build up a more detailed picture of archaeological deposits.

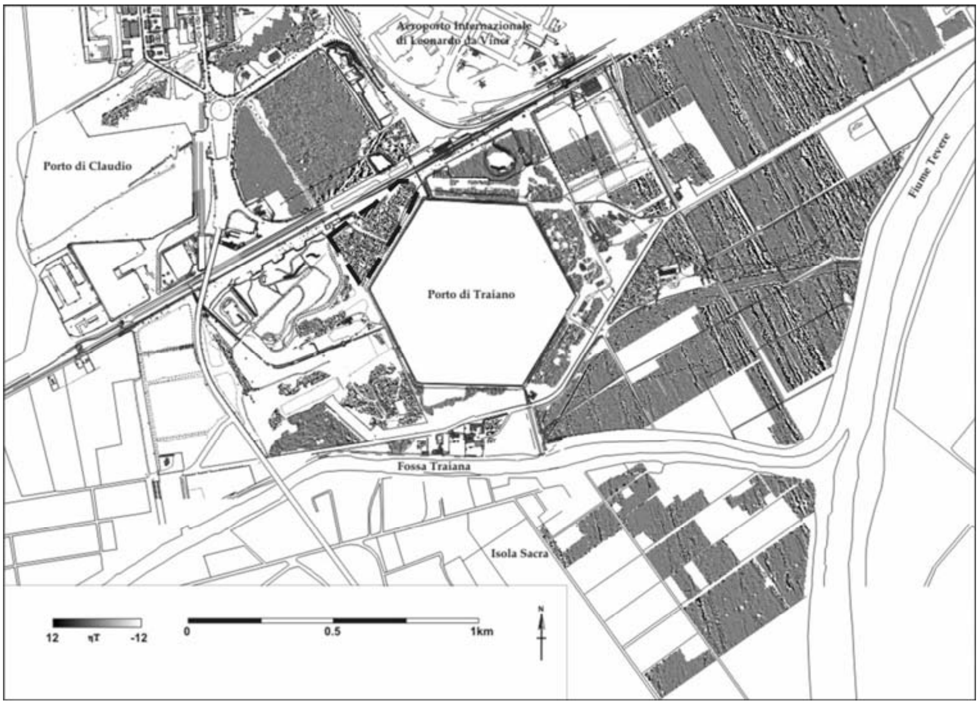


Figure 1. Greyscale map of the magnetometer survey conducted at Portus between 1998 and 2008, showing the area of current work in Isola Sacra. The study area where the integrated survey was conducted is marked with a dashed line

(Conyers & Goodman, 1997; Imai *et al.*, 1987). All of this data can be combined with high resolution microtopography as part of the data modeling process, allowing any variations in signal caused by topographic change to be factored in to the final data model (Sutherland *et al.*, 1999). Geochemical analysis can also be applied using the same survey framework across a study area, facilitating a clearer understanding of different zonation in a site or landscape (Carlucci *et al.*, 2007, 82-84).

2 THE ARCHAEOLOGICAL AND GEOPHYSICAL SURVEYS AT PORTUS

An extensive programme of archaeological geophysics has been conducted at Portus, on the Tyrrhenian coast to the north of the river Tiber, since 1998 (Keay *et al.*, 2005). Work has been funded jointly by the Arts and Humanities Research Council (AHRC) and the Soprintendenza Archeologica di Ostia in the context of a collaborative agreement between the Soprintendenza and the British School at Rome. The fieldwork has been carried out by a team from the University of Southampton, the British School at Rome and the University of Cambridge, with the current excavations being directed by Prof. Simon Keay and Dr Graeme Earl. The principal aim of the survey work was to produce a high resolution detailed plan of the site in its landscape context using magnetometry. Almost 200 hectares of survey were conducted between 1998 and 2006. Under the current programme of research magnetometry is being applied to the south of the Fossa Traiana across the Isola Sacra to allow the nature and extent of archaeological deposits in this zone to be explored (figure 1). A number of features are also being located that demonstrate the process of coastal formation to the south of the Tiber.

The use of a number of different geophysical and topographical survey techniques is being applied in a more intensive manner within the confines of the archaeological park at Portus, immediately to the west of the Trajanic harbour basin. The area under investigation is situated between the so-called Imperial Palace and the Monte Giulio, incorporating the structures located along the western side of the Trajanic basin. The reasons for focusing on this zone are complex, relating to the chronological phasing of the port, and the nature of the structural sequence in this part of the harbour. Prior to commencement of the current excavations directed by Prof. Keay and Dr Earl, an intensive topographical and geophysical survey was undertaken across the entire zone. The work comprised the establishing of an arbitrary grid across the area with a total station, ensuring the spatial integration of the different surveys and the excavation. A micro-topographic survey was then conducted using a total station (figure 2). These surveys all formed the base for an integrated system of geophysical and auger survey. Firstly a series of resistance tomography transects were surveyed across the site using an expanding Wenner array (Aspinall & Crummett, 1997), providing a number of profiles demonstrating the varying resistivity values of deposits up to a depth of 7m (figure 3).

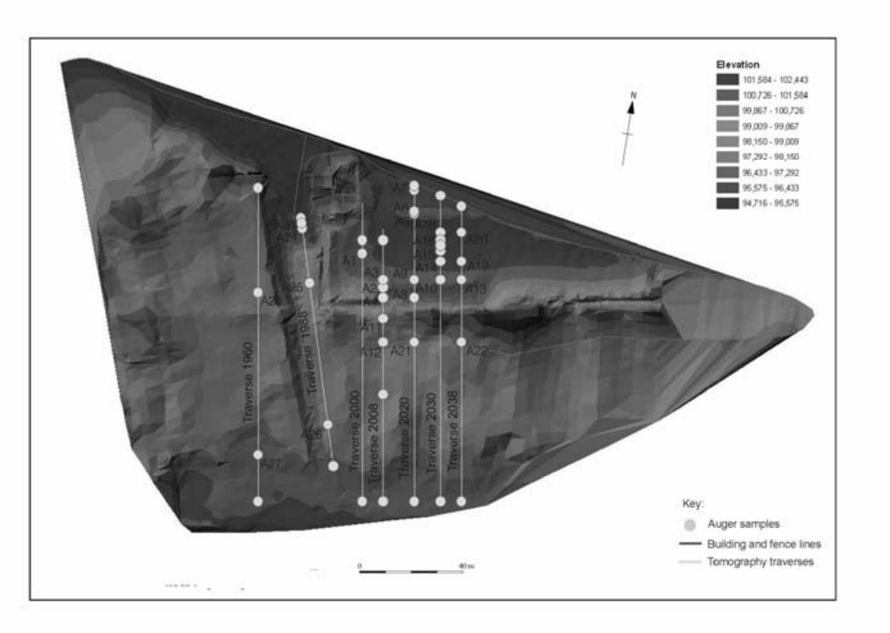


Figure 2. Digital Elevation Model of the area between the Claudian and Trajanic harbours, indicating the position of the resistance tomography profiles and the points where borehole samples were taken

The data were inverted using a least-squares method (Loke & Dahlin, 2002), and the topographical survey was integrated into the model to provide topographic correction for the resistance values. A series of boreholes were also conducted along each of the profile lines to allow comparison of the sedimentary deposits and structural remains with the resistance values. A full GPR survey has also been conducted over the area, with profiles spaced at 0.5m intervals, using a 500 Mhz antenna. A standard twin probe resistivity survey was undertaken in the same area, with measurements taken at 0.5m intervals on 0.5m traverses.

The integrated datasets have allowed a detailed picture of the archaeological deposits to be built up over the study area, showing the remains of a harbour mole and jetty alongside the defensive land wall at the site, and presenting evidence for structural remains alongside the edge of the Trajanic harbour. The results of the survey provided guidance on the best approach for excavation at the site.

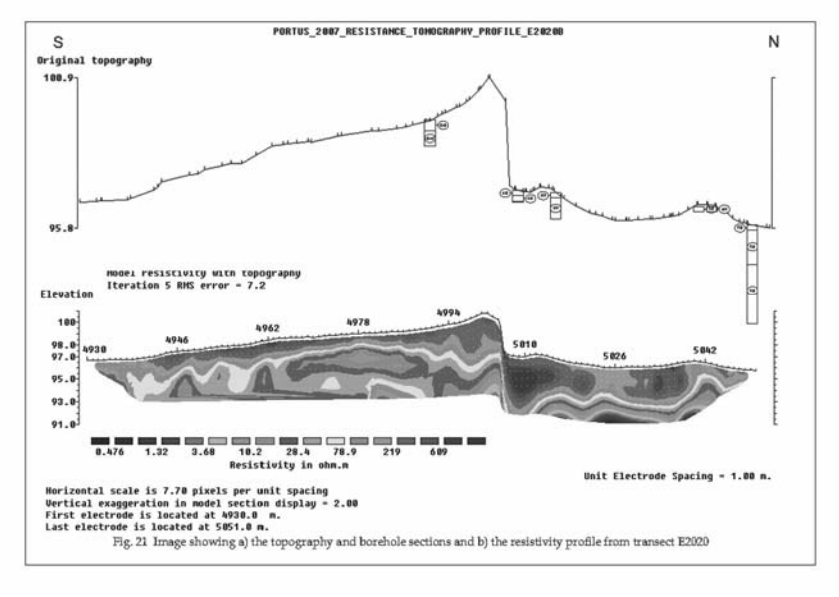


Figure 3. Image showing the tomography profile, below from transect 2020 East, with the high resistance measurements from the defensive wall, jetty and mole indicated in darker shades. The borehole sequences are indicated in the topographic model above

3 CONCLUSIONS

The integrated strategy of survey at Portus demonstrates the effectiveness of applying different techniques to facilitate our understanding of an archaeological landscape. The extensive use of magnetometry has established the extent of the port and the archaeological and geomorphological features along the floodplain of the Tiber. The targeted use of more intensive survey methods has allowed a model of the archaeological deposits of an area within the port complex to be visualized, showing the full depth, extent and nature of the sediments and structural remains at a key focal point of the Imperial harbour.

4 REFERENCES

Aspinall, A., Crummett, J. G. 1997. The Electrical Pseudo-section. *Archaeological Prospection*, 4: 37-47.

Bates, M.R. Bates, C.R. 2000. Multidisciplinary Approaches to the Geoarchaeological Evaluation of Deeply Stratified Sedimentary Sequences: Examples from Pleistocene and Holocene Deposits in Southern England, United Kingdom, *Journal of Archaeological Science,* 27: 845-858.

Bowden, M. 1999. *Unravelling the Landscape: an inquisitive approach to archaeology*. Stroud. Tempus.

Bunbury, J., Graham, A., Strutt, K. 2008. Karnak Land and Waterscapes Survey 2008 Season: report for the Institut Français d'archéologie Orientale. Unpublished archive report.

Carlucci, C., De Lucia Brolli, M.A., Keay, S., Millett, M., Strutt , K. 2007. An archaeological survey of the Faliscan settlement at Vignale, Falerii Veteres, (Province of Viterbo). *Papers of the British School at Rome*, 75: 39-121.

Conyers, L.B. Goodman, D. 1997. *Ground-Penetrating Radar: An Introduction for Archaeologists*, Oxford. Altamira Press.

Hay, S., Keay, M., Millett, M. Strutt, K. 2006. Roman Urban Landscapes in Italy: an integrated approach. In Campana, S. and Forte, M. (Eds), From Space to Place: 2nd International Conference on Remote Sensing in Archaeology. Proceedings of the 2nd International Workshop, CNR, Rome, Italy, December 4-7, 2006: 149-156.

Imai, T., Sakayama, T. and Kanemori, T. 1987. Use of ground-probing radar and resistivity surveys for archaeological investigations, *Geophysics* 52 (2) : 137-150.

Keay, S., Millett, M. Strutt, K. 2004. Recent Archaeological Survey at Portus. In Gallina-Zevi, A. and Turchetti, R. (Eds), Le strutture dei porti e degli approdi antichi (II Seminario ANSER II). Soveria Mannelli; Rubbettino Editore: 221–232.

Keay, S., Millett, M., Paroli, L., Strutt, K 2005. Portus: An Archaeological Survey of the Imperial Port of Rome. Archaeological Monographs of the British School at Rome.

Keay, S., Millett, M. Strutt, K. 2006. An archaeological survey of Capena (La Civitucola, Provincia di Roma). *Papers of the British School at Rome*, 74: 73-118.

Keay, S.J., Millett, M. Strutt, K. 2008, Recent Archaeological Survey at Portus. In Hohlfelder, R.L. The Maritime World of Ancient Rome. Proceedings of 'The Maritime World of Ancient Rome' Conference held at the American Academy in Rome 27-29 March 2003. University of Michigan/American Academy in Rome: 97-104.

Loke, M.H. Dahlin, T. 2002. A comparison of the Gauss-Newton and quasi-Newton methods in resistivity imaging inversion, *Journal of Applied Geophysics*, 49: 149-162.

Papadopoulos, N.G., Tsourlos, P., Tsokas, G.N., Sarris, A. 2006. Two-dimensional and Three-dimensional Resistivity Imaging in Archaeological Site Investigation, *Archaeological Prospection*, 13: 163-181.

Powlesland, D. Lyall,, J. 1996. The application of high resolution fluxgate gradiometry as an aid to excavation planning and strategy formulation. Internet Archaeology **1**. (http://intarch.ac.uk/journal/issue1/lyall_toc.html)

Sutherland, T.L., Schmidt, A., Dockrill, S.J.1999. Resistivity pseudosections and their topographic correction: a report on a case study at Scatness, Shetland, *Archaeological Prospection* **5**, 4: 229-237.

Scollar, I., Tabbagh, A., Hesse, A., Herzog, I. 1990. *Archaeological Prospecting and Remote Sensing*, Cambridge University Press.

Walker, R. 2000, Multiplexed Resistivity Survey at the Roman Town of Wroxeter, *Archaeological Prospection*, **7**: 119-132.

Integrated investigation to study and characterise the Archaeological site of P.zza d'Armi - Veio (Rome, Italy)

S. Piro[1], G. Bartoloni[2], V. Acconcia[2], S.T. Kortenaar[2]

1 ITABC-CNR, P.O. Box 10 00016 Monterotondo Sc. (Roma, Italy).E-mail: Salvatore.piro@itabc.cnr.it

2 Dipartimento di Scienze Storiche, Archeologiche, Antropologiche, Università Sapienza (Rome, Italy)

Keywords: Veio, Magnetic, Georadar, Integration, archaeological excavation

ABSTRACT.

The studied area is located in the archaeological park of Veio (near Rome, Italy), which is characterized by the presence of many structures, necropolis and remains. In particular in the Ancient Acropolis, the walls around the site, the ancient gate, the portion of a main road, the cistern, and the remains of some dwellings are present. The site has been occupied by Etruscans from VI century b.C.

The fundamental geophysical goal in near-surface investigations and particularly in archaeological prospection is to construct, as complete as possible, maps of subsurface targets in 2D and 3D. The main effort in archaeology is also the integration of different, absolutely non-invasive techniques, especially if they are employed in the high resolution three-dimensional tomographic mode.

In the present work a combination of Fluxgate Differential Magnetic (FDM), Ground Penetrating Radar (GPR) and Dipole-Dipole Geoelectric (DDG) methods has been employed with the aim of detecting archaeological structures (wall-remains, traces of ancient road and underground shafts) which characterise the area of Ancient Acropolis of Veio, (Rome). With all geophysical techniques a high-resolution data acquisition technique has been adopted with the aim of reconstructing a global vision of the investigated area (about 2 hectars).

Some signal processing and tomographic representation techniques have been used for data elaboration and interpretation. The results of the geophysical surveys have been confirmed by direct archaeological excavations carried out only at anomalous zones.

1 INTRODUCTION

Geophysical prospecting methods have been considered as a valuable techniques for non-destructive detection of shallow-depth bodies of archaeological interest. This aspect rises from the physical property contrast with respect to the surrounding medium, generated by the buried structures.

The main effort in geophysical prospecting for archaeology is the integration of different, totally non-invasive techniques, especially if managed so as to provide high resolution tomographic representation mode (Cammarano *et al.*, 1998; Gaffney *et al.* 2004; Kvamme, 2006).

The purpose of the present work is to demonstrate the advantages of combining geophysical methods which measure the variations of potential field (gradiometric method) with active methods which measure the variations of physical properties due to the body's geometry and volume (GPR and geoelectric methods), employing an high resolution data acquisition technique, to investigate the area of Ancient Acropolis of Veio, (Rome).

2 SITE CHARACTERISTIC

The site is located in the Archaeological Park of Veio (Rome, Italy), which is characterized by the presence of many structures, necropolis and remains. In particular in the ancient acropolis, the walls around the site, the ancient gate, the portion of a main road, the cistern, and the remains of some dwellings are present. The site has been occupied by Etruscans from IX-VIII centuries b.C., Fig.1.

The outcropping geology of this area is formed by a series of lithoid tuffs, with resistivity values of about 30-40 Ωm. The tuffs are covered by a layer of 0.30-0.35 m thick top soil. From the results of previous archaeological studies (Bartoloni, 1979; Stefani, 1944) the structures are made with the same material (tuffs) and rest on geological outcropping at a depth between 0.40 m and 1.5 m. In this situation, due to these bodies, the geophysical anomalies are generally small and may be masked by geoenvironmental disturbances (Piro, 1998).

The objective of the survey was firstly to verify if it was possible to apply the selected geophysical techniques in the particular geoenvironmental conditions, secondly to locate the assumed structures (ancient road and human dwellings).

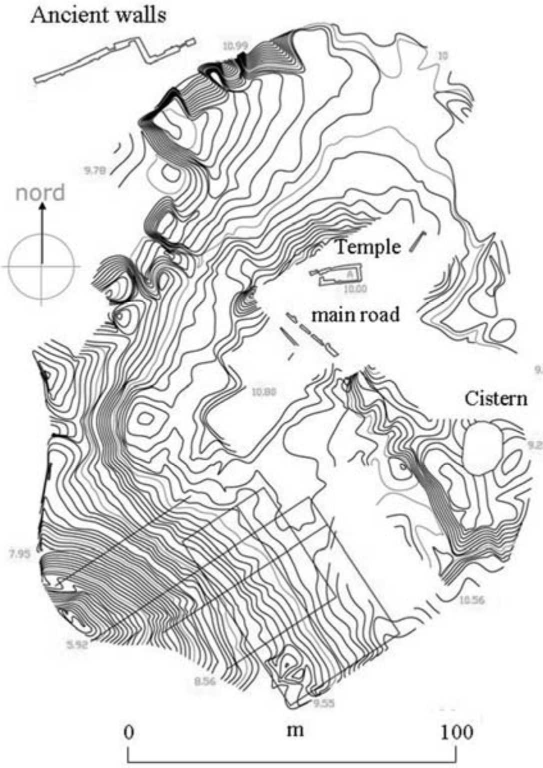


Fig. 1 – Archaeological Park of Veio. Topographical map of P.zza d'Armi site.

3 GROUND REMOTE SENSING SURVEYS (MAGNETIC, GPR AND RESISTIVITY)

In the case of Ancient Acropolis of Veio, taking into account that some shallow archaeological structures are represented by walls made with blocks of volcanogenic tuff, the expected magnetic anomalies will be characterized by a series of dipoles arranged along these walls. However, the measurements collected in archaeological contexts are often masked by noise; for such main reason, it is advisable during the survey to employ portable gradiometers to enhance the signals of shallow structures (Piro, 1998).

For the specific magnetic survey, the measurements were carried out using the Geoscan FM 36 and FM 256 fluxgate gradiometers. These instruments measure the vertical gradient of the Z magnetic component with a fixed inter-sensors vertical spacing of 0.5 *m*. During the survey the bottom sensor was used at a constant height (0.30 *m*) from the soil. The surveyed area was subdivided into 112 squares of side 10 *m*. In each square, 20 parallel profiles spaced 0.5 *m* apart oriented in a S-N direction were collected. Taking into account the depth and dimensions of the assumed targets, measurements were taken at a sampling interval of 0.5 *m* along each profiles.

After the usual pre-elaboration techniques such as despiking, filtering and reranging the results have been represented as a contour maps of the residual values of the gradient of the Z component for the 112 assembled squares, Fig.2. The analysis of this map shows that the area is characterized by many dipolar anomalies in a range of -27, +20 $nT\ m^{-1}$. These anomalies, as it is possible to see in all portion of the investigated area, are spatially organized as a pseudolinear structures or semicircular structures.

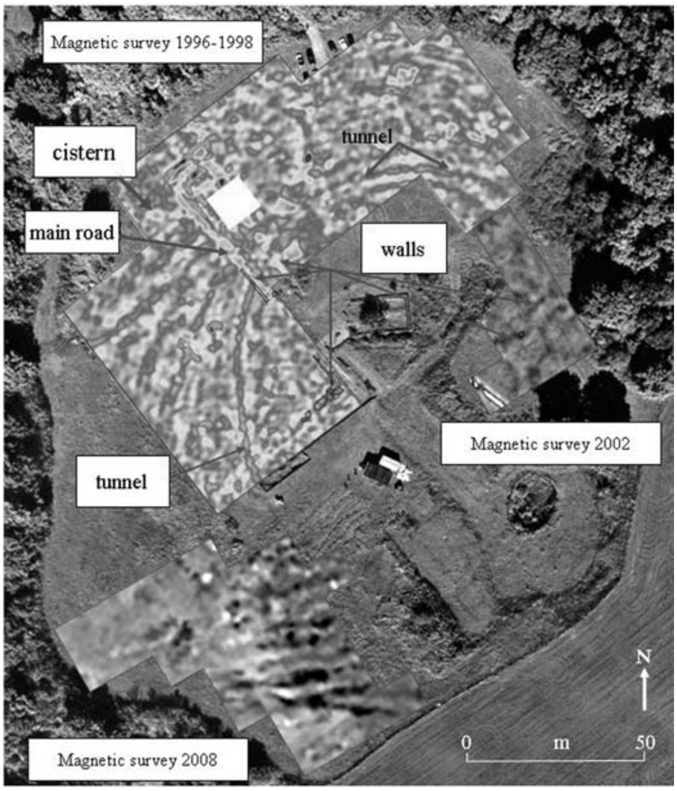


Fig. 2 – Veio P.zza d'Armi.Area investigated with Fluxgate Differential Magnetic method.

Some portion of Piazza d'Armi site have been investigated employing the Ground Penetrating Radar technology, Fig.3. The 20 x 20 *m* area (A) was surveyed with a GSSI SIR 10A, equipped with 500 *MHz* bistatic antenna with costant offset. All reflections within a 30 *ns* time window were recorded. The velocity of electromagnetic waves in the ground (5.5 $cm\ ns^{-1}$) was obtained from previous investigations (Piro, 1998). The horizontal spacing between parallel GPR profiles at the site was 0.5 *m*. The radar system was used in a continuous profiling mode: data were continuously collected along the profile traverse at 16 *scan/sec*. Variations in the radar velocity over the ground, and therefore the number of scans measured between 1-*m* field markers, were later adjusted with software to a constant 60 *scans/sec*. Successively, the scans between 1-*m* field markers, were stacked, obtaining a trace every 0.25 *m*. A total of 41 parallel profiles were made accross the site.

The area with dimension of 30 x 40 *m* (B), has been investigated (2002) employing the same system equipped with 500 *MHz* bistatic antenna with costant offset. A total of 61 adjacent profiles at the site were collected alternately in reversed and un-reversed directions across the survey grids. The horizontal spacing between parallel profiles at the site was 0.5 *m*. Radar reflections along the profiles were recorded in continuous acquisition mode across the ground at 80 $scan\ s^{-1}$; horizontal stacking was set to 4 scans. Along each profile markers were spaced every 1 *m* to provide spatial reference. All radar reflections within the 70 *ns* (two-way-travel time) time windows were recorded digitally in the field as 8 bit data and 512 samples per radar scans.

With the aim of obtaining a planimetric image of all possible anomalous bodies the time-slice representation technique was applied using all field profiles. Time-slices are calculated by creating 2-D horizontal contour maps of the wave energy from a specified time value across parallel profiles, employing GPR-SLICE v5.0 Ground Penetrating Radar Imaging Software. Time slice data sets were generated by spatially averaging the squared wave amplitudes of radar reflections in the horizontal as well as the vertical. Data binning was chosen to generate averages that were 1-2 wavelenths in time, and about half the size of the profile spacing. The data were gridded using a Kriging algorithm that included a search of all data within a 0.75 *m* radius of the desired point to be interpolated on the grid. Background filtering was used to remove line noises that were found to exist in the raw unprocessed images. The Fig.3 shows the time-slice corresponding to the time window 9-16 ns (twt). With the arrows, some anomalies are indicated which, in the case of site A, have presented a good matching with the archaeological structures after the direct excavations made in the period 1996-2002.

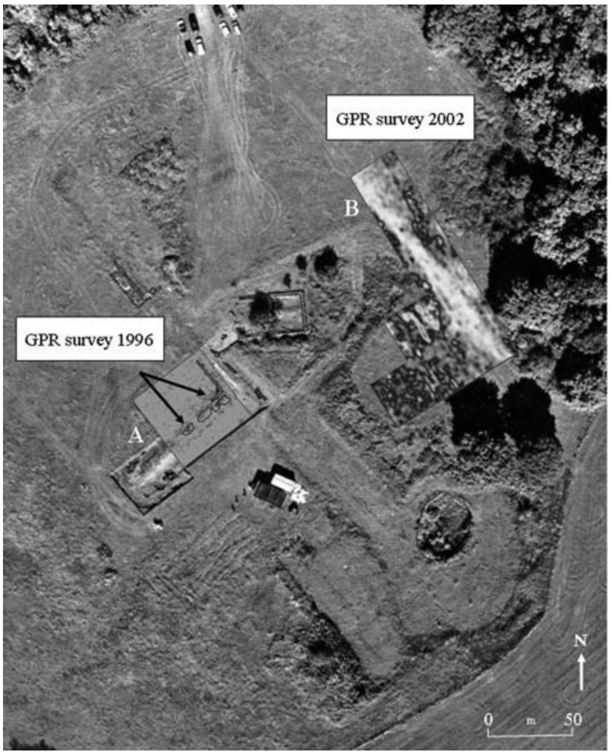


Fig. 3 – Veio P.zza d'Armi.GPR time slice of the investigated area Estimated depth 0.70 m.

In the 20x20 *m* area (A) 11 parallel dipole-dipole profiles were executed with a constant separation of 2 *m* from each other. The measurements were performed with the BRGM SYSCAL/R2 resistivity-meter, which can operate in the stacking signal enhancement mode. Each apparent resistivity datum was obtained with dipoles of 0.5 *m* of length and attributed at a pseudodepth equal to half the spacing between the centres of the emitting and receiving dipoles along the median vertical axis through the line joining them. The step-by-step continuous displacement of the dipoles along each profile provided a dense network of about 175 experimental data points in the vertical pseudosection.

In the 10 x 20 *m* area (B) 11 parallel dipole-dipole profiles were executed with a costant separation of 1 *m* from each other. The measurements were performed with the Sting 31 IP resistivity-meter (A.G.I. – USA), equipped with 28 electrodes. Each apparent resistivity datum was obtained with dipoles of 0.5 *m* of length and attributed at a pseudodepth equal to half the spacing between the centres of the emitting and receiving dipoles along the median vertical axis through the line joining them.

In the northern part of this area, 3 parallel dipole-dipole profiles were executed with a costant separation of 5 *m* from each other. The measurements were performed with the Sting 31 IP resistivity-meter (A.G.I. – USA), equipped with 28 electrodes, with the aim to verify the presence of possible tunnel, that has been located with the magnetic survey.

4 CONCLUSION

Taking into account the results obtained with this integrated survey, it is possible to make the following two considerations: (i) the 2D u.h.r. data acquisition technique permits to condition the investigated area with a high number of measurements. This procedure allows to collect a set of detailed information about the lateral extensions of the anomalous bodies, which are normally not available by the traditional sampling intervals; (ii) the improvement of the processing techniques towards a 3D tomographic imaging and the integration of different geophysical methods enable one to better define position, extension, depth and thickness of any anomalous body (archaeological remnant) within the geological context. Also, the discrimination power between close but distinct archaeological structures is notably enhanced.

Archaeological excavations made during 1996-2002 have confirmed all geophysical anomalies. The oldest features have been dated to Iron Age (IX-VIII b.C.). Some little hunts, remains of palisades and some pits are related to this period, till to the VII century b.C.. The main road ("decumano") with few orthogonal roads have been dated to VII century b.C. and represent the first regular grid, in Etruria, respect to other sites as Marzabotto. In the investigated area A, the located roads are limited in the western part by two blocks of houses, Fig. 4.

The project is still in progress and new geophysical surveys and archaeological excavations are planned in the next future.

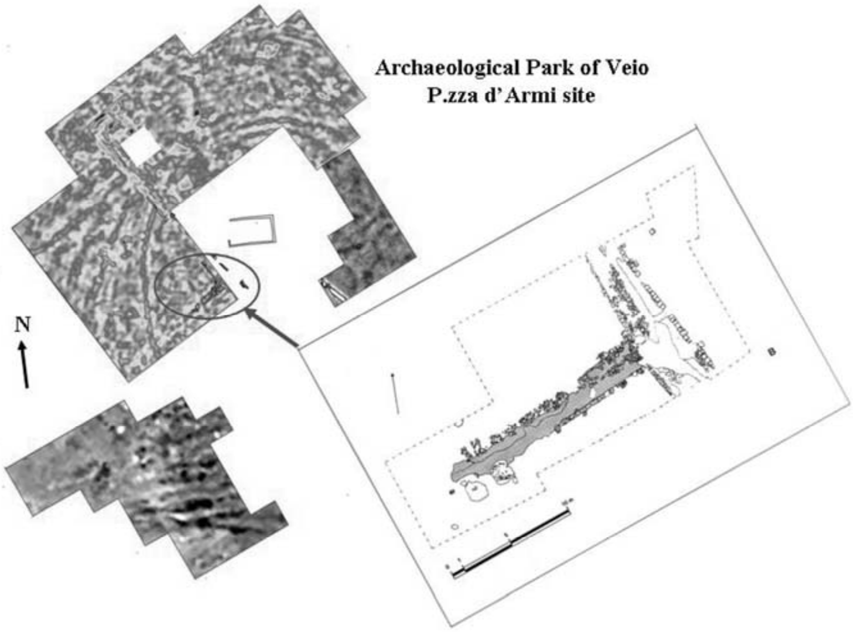


Fig. 4 – Veio P.zza d'Armi. Magnetic maps of all investigated area with the details after the archaeological excavations of the main and lateral roads.

5 REFERENCES

Cammarano, F., Mauriello, P., Patella, D., Piro, S., Rosso, F., Versino, L., 1998. Integration of high resolution geophysical methods. Detection of shallow depth bodies of archaeological interest. *Annali di Geofisica*, 41, 3 : 359-368.

Gaffney, V., Patterson, H., Piro, S., Goodman, D., Nishimura, Y., 2004. Multimethodological approach to study and characterise Forum Novum (Vescovio, Central Italy). *Archaeological Prospection*, 11 : 201-212.

Kvamme, K.L., 2006. Integrating Multidimensional Geophysical data. *Archaeological Prospection,* 13: 57-72.

Piro, S., Samir, A., Versino, L. 1998. Position and spatial orientation of magnetic bodies from archaeological magnetic surveys. *Annali di Geofisica,* 41(3): 343-358.

Piro, S., Cammarano, F., Mauriello, P. 2000. Quantitative integration of geophysical methods for archaeological prospection. Archaeological Prospection, 7 (4) : 203-213.

Piro, S. 1998. Prospezioni Geofisiche Integrate nell'area di Veio, Piazza d'Armi. *Studi Etruschi*, LXII – MCMXCVI (serie III) : 328 – 336.

Novel tomographic based algorithms and processing strategies for multi-frequency antennas GPR measurements

F. Soldovieri[1], L. Orlando[2]
1 Istituto per il Rilevamento Elettromagnetico dell'Ambiente, Consiglio Nazionale delle Ricerche, Via Diocleziano 328, 80124 Napoli, Italy. Ph: +39 081 5707999, fax: +39 081 5705734, e-mail: soldovieri.f@irea.cnr.it
2 Dipartimento di Idraulica Trasporti e Strade, La Sapienza University, Via Eudossiana 18, Roma, Italy,
e -mail: luciana.orlando@uniroma1.it

Keywords: Ground Penetrating Radar (GPR), in situ subsurface prospecting, microwave tomography

ABSTRACT: This work is focused on an advanced processing approach and two solution strategies able to exploit multi-frequency antennas in GPR prospecting with the aim of improving the interpretability of the reconstructed images. The processing approach is based on microwave tomography and permits to have good performances in the focalization of localized objects and the stability with respect on noise on data. In addition, by exploiting the microwave tomographic approach, we introduce two solution strategies able to combine the data by the two antennas working in different frequency band. The first one is based on the simultaneous inversion of overall the data content gathered by the two antennas; the other one is based on the correlation of the images reconstructed under the single frequency band. Numerical and experimental data allow a preliminary analysis of the performances of the two strategies.

1 INTRODUCTION

The exploitation of GPR in archaeology and cultural heritages diagnostics is now well assessed as shown by the large number of realistic cases (Orlando, 2007; Orlando & Soldovieri, 2008; Piro *et al.* 2003).

On the other hand, one of the main requirements from archaeological community is concerned with the "visualization" of the processed data, i.e., the possibility to achieve images of the underground that are reliable, easily interpretable, at high resolution and lastly stable with respect to the noise on data and uncertainties on both measurement parameters and features of the investigated scenario.

In this work, we propose advancements with the aim of improving the results of the overall GPR diagnostics procedure, thus mitigating the necessity of the "interpretation" of the reconstruction outcome, which is one of the crucial limitations related to the exploitation of GPR.

The first topic is concerned with the exploitation of a microwave tomography based approach able to give high resolution and detailed images of the investigated scenario, especially when the target of the investigation is the localization and the shape reconstruction of localized objects (Leone & Soldovieri, 2003; Soldovieri *et al.*, 2007). Microwave tomography based approach faces the inverse scattering problem, where a contrast function accounting for the "difference" between the electromagnetic properties of the targets and of the host medium is determined starting from the scattered field measurements. In particular, simplified models of the electromagnetic scattering are adopted with the aim to approach the realistic scenarios where the investigation of large domains should be addressed in a reasonable computational time and in a reliable way.

The other topic is concerned with the set-up of two different strategies able to process/combine simultaneously and in a synergic way the measurements collected by two antennas with different working frequency bands (for the cases here considered we have peak frequency at 200 and 600 MHz). First, the feasibility and the performances of these strategies will be pointed out with synthetic data. Then, we will show the reconstruction by the two solution strategies in a realistic case with the measurements collected during a survey in Palatino archaeological site (Rome); the aim of these measurements was the detection and localization of buried structures along the "Via Nova" affected by structural instability.

2 FORMULATION OF THE MICROWAVE TOMOGRAPHIC APPROACH

The microwave tomographic approach has been largely described in many papers and here we report only the key elements of the approach; the reader interested can find more detailed description in (Leone & Soldovieri, 2003; Soldovieri *et al.*, 2007).

In order to set up the tomographic inversion procedure, the problem can be conveniently modelled considering the air-soil interface as the planar interface separating two half-spaces (at $z = 0$); the upper half space being the air, while the lower one schematizing the soil as a homogeneous medium with relative dielectric permittivity ε_b and conductivity σ_b. Assuming for the sake of simplicity a 2D geometry, the cross-section of the embedded objects are invariant along the *y*-axis and supposed to be enclosed in a rectangular investigation domain $D = [-a,a]X[z_{min}, z_{min} + 2b]$. The unknowns of the problem are the relative dielectric permittivity $\varepsilon_D(x,z)$ and the conductivity $\sigma_D(x,z)$ functions inside *D*. The source of the incident field E_{inc} is supposed to be a time-harmonic (time dependence exp($j\omega t$), $\omega = 2\pi f$) filamentary *y*-directed electric current (TM-polarization), of infinite extent and invariant along the *y*-axis. A multi-monostatic measurement configuration is considered where the transmitting and receiving antennas are located at the same point and are moved with an uniform spatial step at various positions x_s within the interval Σ= [$-x_M, x_M$] located along the interface air/soil (at z=0).

Under the above assumptions and within the BA, the unknown-data relationship is provided by the following equation (Soldovieri et al. 2007; Leone & Soldovieri, 2003):

$$E_s(x_s,\omega) = k_s^2 \int G_e(x_s,\omega,x',z')E_{inc}(x_s,\omega,x',z')\chi(x',z')dx'dz' \qquad (1)$$

where E_s denotes the scattered electric field probed at x_s; k_s indicates the wave-number in the lower; G_e is the (known) Green's function and the "contrast" function χ is defined as:

$$\chi(x',z') = \frac{\varepsilon_{eq}(x',z') - \varepsilon_{eq}}{\varepsilon_{eq}} \qquad (2)$$

where $\varepsilon_{eq}(x',z') = \varepsilon_0\varepsilon_D(x',z') - j\dfrac{\sigma_D(x',z')}{\omega\varepsilon_0}$ and $\varepsilon_{eqb}=\varepsilon_0\varepsilon_b - j\dfrac{\sigma_b}{\omega\varepsilon_0}$.

The inversion of the linear integral equation is performed by the Truncated Singular Value Decomposition tool (Bertero & Boccacci 1998) that allows us to mitigate the effect of the noise on data. The tomographic images are finally given in terms of the normalized modulus of the contrast function; the regions where the modulus of the contrast function is significantly different from zero accounts for the location and geometry of the buried objects.

Let us turn to present two solution strategies aiming to exploit the measurements from two antennas with different frequency band Ω_1 e Ω_2.

The first strategy is based on the simultaneous exploitation of the two work frequency bands and consists in the inversion of the integral equation where the data are the measurements collected in the two bands Ω_1 e Ω_2. As matter of fact, for the realistic antennas considered here (at 200 Mhz and 600 MHz), the two frequency bands do not overlap, thus it is expected that no improvement in the resolution of the images is achieved; furthermore, due to the "independence" of the data in the two bands, the reconstructed image can be "seen" as the "summation" of the images reconstructed under the single frequency bands Ω_i, i=1,2.

The second solution strategy consists in a two-step procedure; the first step consists in obtaining the two images through the inversion for each single frequency band; then the overall reconstructed image is achieved by performing the multiplication "pixel by pixel" of the modulus of the contrast function retrieved under one band for the corresponding quantity retrieved under the other band. This way to proceed allows to point out the common part of the object reconstructed under the single frequency bands, to achieve more focalized images of the object and to remove artifacts present in the single inversions; on the other hand, in the case of objects characterized by a different level in the reconstructed contrast function (due to the different depth and/or the relative positions with respect to the antennas) , the overall reconstruction has the drawback that the object with the smaller "intensity" could disappear in the image.

All the above consideration will be exemplified by the analysis presented in the following Section.

3 RESULTS AND CONCLUSIONS

This Section is devoted to present some preliminary reconstruction results concerned with the application of the two solution strategies, both exploiting the tomographic approach, to synthetic and experimental data.

The synthetic data are concerned with two buried objects in a soil with relative dielectric permittivity equal to 11 and conductivity equal to 0.01 S/m. The buried dielectric objects have relative dielectric permittivity equal to 4 and circular cross section with radius 0.05 and 0.1 m; the objects are at different depth as can be seen in Figs. 1-4. An investigation domain $D=[-.8,.8]X[0.01,0.6]m^2$ is assumed. The adopted measurement configuration has a measurement domain of 1.6m in 41 points with a spatial step of 0.04m. Two different filamentary antennas have been simulated and are fed with Ricker signals of center frequency of 200 MHz and 600 MHz, respectively. The data are synthesized in time domain by means of the GPRMAX code based on FDTD (Giannopoulos 2003). The work frequency band adopted in the inversion is 50-860 MHz with a step of 30 MHz. The TSVD assumes a threshold at -35 dB to cut off the lower singular values.

Figures 1 and 2 depict the images achieved under the single frequency band at 200 MHz and 600 MHz, respectively; we can observe a higher resolution in the image at 600 MHz but also the presence of artifacts for the deeper cylinder. Figures 3 and 4 reports the two reconstruction by exploiting the two solution strategies based on the "multiplication" (second solution strategy) and "summation" (first solution strategy), respectively. We can note that, compared to the reconstruction achieved by the "summation" strategy, the reconstruction under the "multiplication" is clever and at higher resolution but the deeper cylinder is imaged at a lower level.

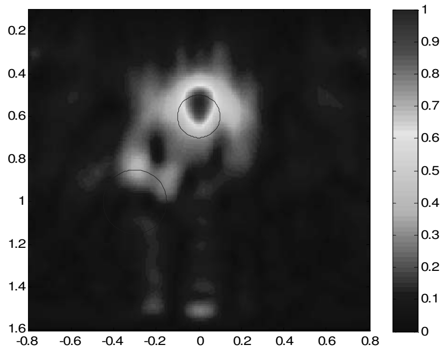


Figure 1. Reconstruction at 200 MHZ

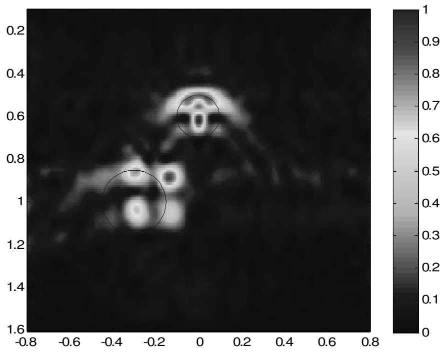


Figure 2. Reconstruction at 600 MHZ

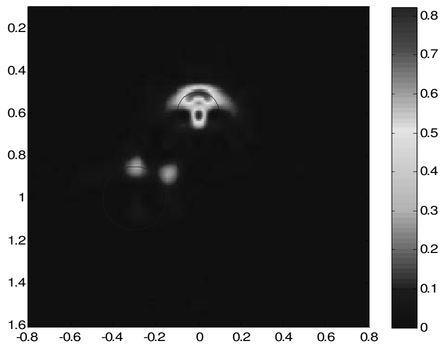


Figure 3. Reconstruction with the "multiplication"

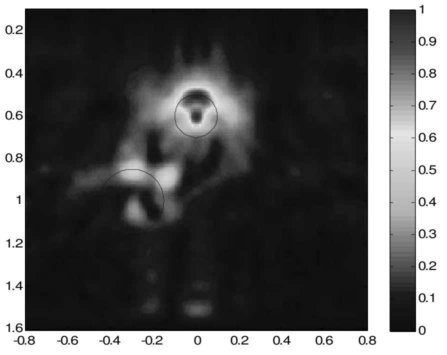


Figure 4. Reconstruction with the "summation"

Finally, we present a result achieved by processing realistic data collected during a survey in Palatino archaeological site (Rome) where the aim was the detection and localization of buried structures along the "Via Nova" affected by structural instability.

The experimental data are concerned with a profile collected by two antennas with peak frequency at 200 MHz and 600 MHz. The part of the vertical profile that has been processed has the extent of 1.6m and the spatial step of the measurements is 0.04 m. An investigation domain with extent of 1.6m along the horizontal axis and ranging in depth till to 0.6 m has been considered. The work frequency band assumed in the inversion is 50-860 MHz with frequency step equal to 30 MHz. The relative dielectric permittivity and the conductivity of the soil are assumed equal to 9 and 0.01 S/m, respectively. In the inversion a threshold of -20 dB is assumed for the TSVD Figures 5-8 are the analogous of the figs 1-4 (reported for the synthetic case). Some considerations are in order: both the single frequency band images permit to detect and localize three objects roughly located at an uniform step; also for the actual data the correlation approach gives better results in localizing the objects..

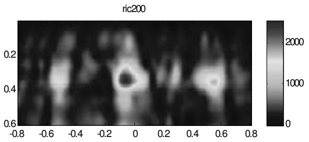


Figure 5. The reconstruction at 200 MHz

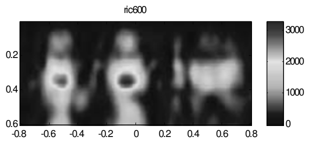


Figure 6. The reconstruction at 600 MHz

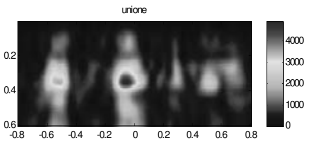


Figure 7. Reconstruction with the" summation"

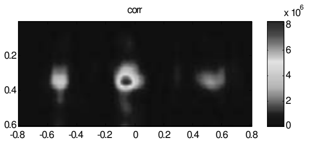


Figure 8. Reconstruction with the "multiplication"

4 REFERENCES

Bertero, M., Boccacci, P. 1998. *Introduction to Inverse Problems in Imaging*. Institute of Physics Publishing, Bristol and Philadelphia.

Giannopoulos, A. 2003. GprMax2D V 1.5 (Electromagnetic simulator for Ground Probing Radar, the software is available at www.gprmax.org).

Leone, G., Soldovieri, F. 2003. Analysis of the distorted Born approximation for subsurface reconstruction: truncation and uncertainties effects. *IEEE Trans. Geoscience and Remote Sensing*, 41: 66-74.

Orlando, L. 2007. Georadar and magnetic data for the planning of an archaeological excavation (Case study in central Italy). *Archaeological Prospection*, 14: 1-13.

Orlando, L., Soldovieri, F. 2008. Two different approaches for georadar data processing: a case study in archaeological prospecting. *Journal of Applied Geophysics,* 64: 1-13.

Piro, S., Goodman, D., Nishimura, Y. 2003. The study and characterization of Emperor Traiano's villa (Altopiani di Arcinazzo, Roma) using high-resolution integrated geophysical surveys. *Archaeological Prospection* 10: 1-25.

Soldovieri, F. , Hugenschmidt, J., Persico, R., Leone G. 2007. A linear inverse scattering algorithm for realistic GPR applications. *Near Surface Geophysics,* 5: 29-42.

A modelling/inverse-scattering approach to investigate the potential of GPR for the location of archaeological human remains

L. Nuzzo[1], T. M. Millington[2], N. J. Cassidy[2], J.K. Pringle[2]

1 School of Physical and Geographical Sciences, Keele University, Keele, ST5 5BG, U.K., l.nuzzo@esci.keele.ac.uk

2 Keele University, Keele, U.K., t.m.millington@epsam.keele.ac.uk, n.j.cassidy@esci.keele.ac.uk, j.k.pringle@esci.keele.ac.uk

Keywords: GPR, modelling, microwave tomography, archaeology, bones

ABSTRACT.

Ground-penetrating radar (GPR) has been used to detect buried human remains in forensic investigations. However, in archaeological prospecting GPR has been used mainly to locate tombs, burial chambers and coffins, rather than the body itself, since the decomposition process makes very difficult the detection of small-sized skeletal remains especially if buried in heterogeneous, conductive soils. Previous papers have demonstrated the usefulness of finite-difference modelling to assess the detectability of human remains for forensic investigations. Numerical simulations can indeed investigate the ability of GPR to resolve diagnostic features of the human body under various subsurface conditions and survey parameters. The modelling results can assist in planning the acquisition of real data and provide test data for evaluating the performance of data processing algorithms.

In this paper, we present the results of a feasibility study for the use of GPR to locate human remains in archaeological contexts, and to investigate its resolution capabilities. We exploit a novel approach based on the integration of modelling and tomographic inversion. GPR responses for the usual monostatic or bistatic survey configuration are simulated for various body cross-sections using either a 2D frequency-domain electromagnetic forward solver or 2D and 3D finite-difference time-domain (FDTD) algorithms. The inversion is performed through an innovative frequency-domain tomographic technique based on the solution of a linear inverse-scattering problem under the Born approximation. Our results show that, although a proper reconstruction of the distribution of the subsoil electromagnetic parameters cannot be achieved in complex realistic situations, this technique allows a better location of buried human remains than conventional GPR processing.

1 INTRODUCTION

Ground-penetrating radar (GPR) has been used to detect buried human remains in forensic investigations and graveyard mapping (Bevan, 1991; Strongman, 1992; Nobes, 1999; Pringle *et al.*, 2008). However, the decomposition of the soft tissues and the collapse, fracturing and displacement of the bones make the detection of human remains even more difficult in archaeological investigations. Therefore, in archaeological prospecting GPR has been used mainly to locate tombs, burial chambers and coffins (Conyers & Goodman, 1997; Goodman *et al.*, 2007) rather than to locate human remains (Mellett, 1992). The main reason is the difficulty to locate small-sized skeletal remains (bones and fragments) especially if buried in heterogeneous, conductive soils. In fact, to resolve the individual bones, high-frequency antennas (~ 1000 MHz and above) would be required. Unfortunately, due to scattering and conduction losses, the signal attenuation could be a serious problem at these frequencies, limiting the investigation depth to less than half a metre. The use of lower-frequency antennas to locate deeper burials would result in a loss of resolution. Therefore, in most cases reported in the literature, the search for human remains has relied primarily on the location of non-specific GPR anomalies, such as soil disturbances (Unterberger, 1992).

Previous papers (Hammon III *et al.*, 2000) have demonstrated the usefulness of finite-difference modelling to assess the detectability of human remains for forensic investigations. Numerical simulations can indeed investigate the ability of GPR to resolve diagnostic features of the human body under various subsurface conditions (different soil types, moisture content, amount of heterogeneity/clutter, surface roughness, burial depth, and decomposition stage) and various survey parameters (antenna frequency, acquisition mode, transmitter-receiver offset and mutual orientation, inline and crossline spacing). The modelling results can provide useful insights for planning the acquisition of real data in order to maximize the information that can be extracted from the GPR anomalies. Moreover, the simulations can provide test data for evaluating the performance of data processing and imaging algorithms.

2 METHODOLOGY

In this paper, we present the early results of a feasibility study for the use of GPR to locate human remains in archaeological contexts, and to investigate its resolution capabilities. To this aim, we exploit a novel approach based on the integration of modelling and tomographic inversion (Nuzzo *et al.*, 2008).

GPR responses for the usual monostatic or bistatic survey configuration are simulated for various body cross-sections using either a 2D frequency-domain electromagnetic forward solver or 2D and 3D finite-difference time-domain (FDTD) algorithms (Cassidy, 2007). In particular, the 3D case is an advanced, full-wave forward modelling algorithm able to incorporate not only off-line reflections from finite-extent bodies, but also more realistic antenna design/survey configuration (Millington & Cassidy, 2008).

The inversion is performed through an innovative frequency-domain microwave tomographic technique based on the solution of an inverse-scattering problem (Colton & Kress, 1992; Bertero & Boccacci, 1998; Crocco & Soldovieri, 2003). It exploits a linear model of the electromagnetic scattering based on the Born approximation, which implies neglecting the mutual interactions between the buried targets and the air/soil interface. Although generally unable to give quantitative information on the electromagnetic properties of the underground targets, linear inverse-scattering methods are much less time consuming than non-linear methods and can provide useful qualitative information on the location and sizes of anomalous targets (Crocco & Soldovieri, 2008).

3 NUMERICAL RESULTS

For the sake of brevity, in the following example we show only the GPR cross-sections generated using a 2D frequency-domain (FD) forward modeler to simulate a skull model in two archaeological situations, namely an air-filled (Figure 1, top) and a clay-filled (Figure 1, bottom) human skull buried in clay-rich sand (dielectric constant 3.3, conductivity 17 mS/m; EM velocity 16.5 cm/ns). In both cases, 13 frequencies at 100 MHz steps (Figure 2 left) were used to simulate a monostatic acquisition with the transmitter/receiver pair moving at 0.1 m interval along a 2 m long survey line located 1 cm above the ground surface. The data were converted in the time domain (TD) through FFT (Figure 2 central) and migrated using the known background velocity (Figure 2 right). The presence of a strong top (and of a much weaker bottom) reflection makes the skull detectable in this homogeneous background, but the coarse spatial and temporal sampling prevents the determination of its correct size and shape through conventional processing.

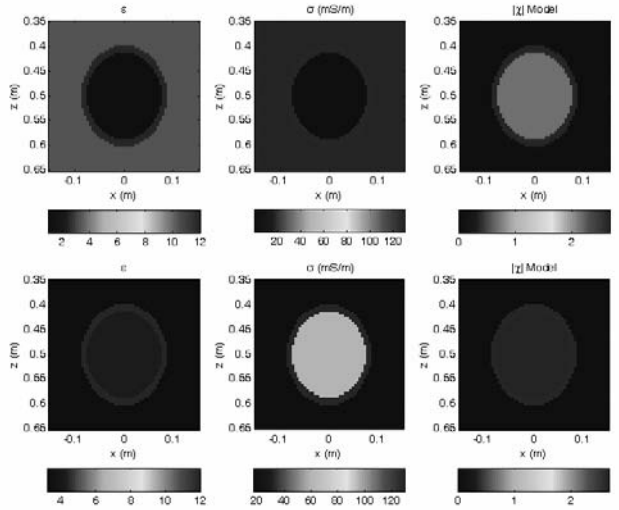


Figure 1. EM parameters (ε, σ) and corresponding modulus of the contrast function χ for two skull models. Top: air-filled; bottom: clay-filled

The scattered field data were inverted according to the linear tomographic technique (Crocco & Soldovieri, 2003) using a truncated singular value decomposition (TSVD) approach to regularize the inversion, by neglecting the contribution pertaining to singular values below a predefined threshold (-20 dB of the highest singular value). The reconstructed data were plotted as the modulus of the contrast function χ normalized to its maximum (Figure 3), where χ is the relative difference between the target and the background complex dielectric permittivity. A good reconstruction of the shallow target boundary is achieved for the air-filled model in both the noise-free case and for low-to-moderate noise levels (signal to noise ratio or SNR≥10). An even better qualitative reconstruction is achieved in the clay-filled case, since both the shallow and deep (although much weaker) boundaries are reconstructed in close proximity to the true position for good/medium-quality data (SNR≥10). This can be explained as a closer proximity to the Born approximation (low contrast) in the clay-filled skull model due to the lower contrast between the filling medium and the background soil. For both models, some reconstruction artifacts appear at very high noise levels (SNR=1). Even for the noise-free case, the results from conventional processing (left in Figure 3) are worse than the tomographic inversion results.

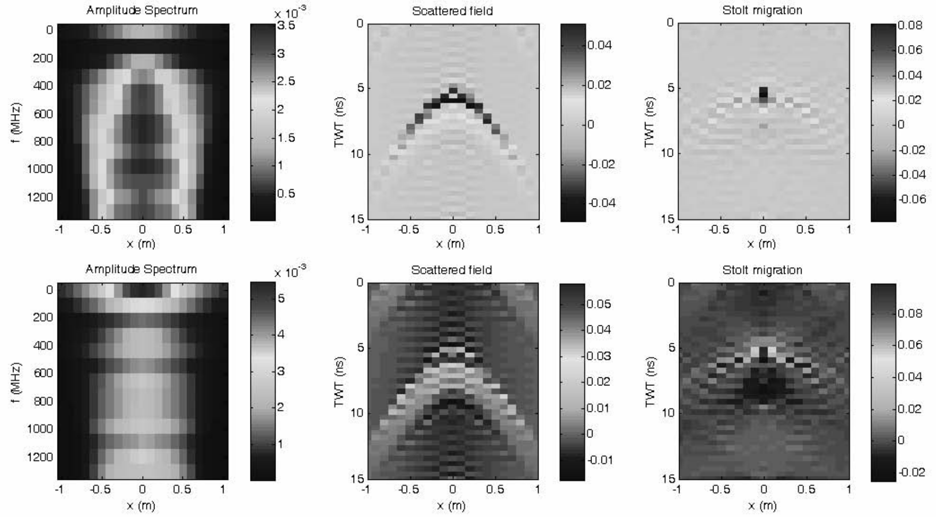


Figure 2. FD and TD scattered field from the skull models in Figure 1, and corresponding migrated data at 16.5 cm/ns. Top: air-filled; bottom: clay-filled.

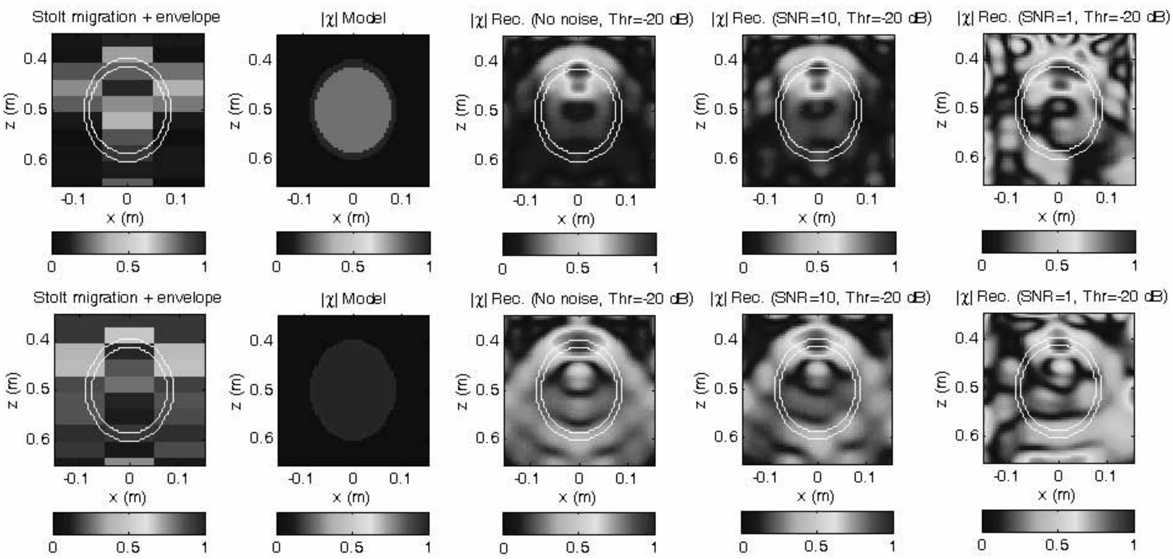


Figure 3. Reconstruction of the skull models in Figure 1 under different Signal-to-Noise ratios and comparison with the true models and the results from conventional processing (left). Top: air-filled; Bottom: clay-filled

A much wider bandwidth, and hence a much narrower pulse-width, would be required for resolving the fine features of the target (i.e. to identify each of the soil-bone, bone-air or bone-clay interfaces). Several other tests are being performed to investigate the influence of different modeling schemes and inversion parameters and to explore the resolution capabilities of the proposed technique in realistic scenarios.

4 CONCLUSIONS

The preliminary numerical results shown in this paper demonstrate that, although a proper reconstruction of the distribution of the subsoil electromagnetic parameters cannot be achieved in complex realistic situations, in more favourable conditions the linear inversion technique not only allows the detection of buried human remains, but produce better focused GPR images than conventional processing techniques, thus providing a better location of their depth and geometrical shape.

5 REFERENCES

Bertero, M., Boccacci, P. 1998. *Introduction to Inverse Problems in Imaging*. Institute of Physics Publishing, Bristol and Philadelphia.

Bevan, B. W. 1991. The search for graves, *Geophysics*, 56: 1310-1319.

Cassidy, N. J. 2007. A review of practical numerical modeling methods for the advanced interpretation of ground-penetrating radar in near-surface environments, *Near-Surface Geophysics*, 5: 5-22.

Colton, D., Kress, R. 1992. *Inverse acoustic and electromagnetic scattering theory*. Springer Verlag.

Conyers, L. B., Goodman, D. 1997. *Ground-Penetrating Radar - An Introduction for Archaeologists*, Alta Mira Press, Walnut Creek, CA.

Crocco, L., Soldovieri, F. 2003. A microwave tomographic approach for imaging targets buried in a layered medium, *Annals of Geophysics*, 46: 559-572.

Crocco, L., Soldovieri, F. 2008. From qualitative to quantitative inverse scattering methods for GPR imaging, in *12th International Conference on Ground Penetrating Radar, June 16-19, 2008, Birmingham, UK.*

Goodman D., Hongo, H., Higashi, N., Inaoka, H., Nishimura, Y. 2007. GPR surveying over burial mounds: correcting for topography and the tilt of the GPR antenna, *Near Surface Geophysics*, 5: 383-388.

Hammon III, W. S., McMechan, G. A., Zeng, X. 2000. Forensic GPR: finite-difference simulations of responses from buried human remains, *Journal of Applied Geophysics*, 45: 171-186.

Mellett, J. S. 1992. Location of human remains with ground-penetrating radar, in *Fourth International Conference on Ground Penetrating Radar, Rovaniemi, Finland. Geological Survey of Finland Special Paper*, 359-365.

Millington, T. M., Cassidy, N. J. 2008. Optimising GPR Modelling: A Practical, Multi-threaded Approach to 3D FDTD Numerical Modelling, in *12th International Conference on Ground Penetrating Radar, June 16-19, 2008, Birmingham, UK.*

Nobes, D. C. 1999. Geophysical surveys of burial sites: a case study of the Oaro urupa, *Geophysics*, 64: 357-367.

Nuzzo, L., Prisco, G., Millington, T. M., Cassidy, N. J., Crocco, L., Soldovieri, F. 2008. Advanced Modeling and Inversion for Bistatic GPR Evaluation of Incipient Pipeline Leakage, in *12th International Conference on Ground Penetrating Radar, June 16-19, 2008, Birmingham, UK.*

Pringle, J. K., Jervis, J., Cassella, J. P., Cassidy, N. J. 2008. Time-lapse geophysical investigations over a simulated urban clandestine grave, *Journal of Forensic Sciences*, in press.

Strongman, K. B. 1992. Forensic applications of ground penetrating radar, in Pilon, J., *Ground Penetrating Radar, Paper Geological Survey of Canada*, 90: 203-211.

Unterberger, R. R. 1992. Ground penetrating radar finds disturbed earth over burials, in *Fourth International Conference on Ground Penetrating Radar, Rovaniemi, Finland. Geological Survey of Finland Special Paper*, 351-357.

Comparing Inverse Scattering Algorithm and Imaging Standard Processing for GPR Data

R. Castaldo[1], M. Fedi[1], B. Garofalo[1], L. Crocco[2], F. Soldovieri[2], R. Persico[3]

1 Università Federico II, Dipartimento di Scienze Della Terra, Largo San Marcellino 10, 80138 Napoli
email: fedi@unina.it
2 Istituto per il Rilevamento Elettromagnetico dell'Ambiente, IREA-CNR, Via Diocleziano 328, 80124, Napoli,
e-mail: soldovieri.f@irea.cnr.it
3 Istituto per i Beni Archeologici e Monumentali IBAM-CNR, Via Monteroni, Campus Universitario, 73100 Lecce,
e-mail: r.persico@ibam.cnr.it

Keywords: inverse scattering, standard processing, GPR.

ABSTRACT

Interpretation of GPR data usually involves the same processing used for seismic data analysis. Alternatively, in the last few years a microwave tomographic approach, based on the Born approximation in the frequency domain has gained interest. The aim of this work is the comparison between the tomographic approach and the imaging procedure as it comes out from a standard reflection seismic processing. In both methods the background scenario is built up of two half spaces. Generally, the inversion algorithm produces well-focused solutions and, often, it seems to mitigate automatically some artifacts resulting from the multiple reflections. Moreover, it is less time consuming with respect to the performed standard migration algorithm. The importance of adopting suitable parameters in the regularization of the linear inverse problem has been investigated too, allowing us to get a good reconstruction in terms of resolution and depth of investigation. The comparison has been performed first with synthetic data and then also from GPR measurements collected during a survey in the archaeological site of Pontecagnano (SA).

1 INTRODUCTION

In the framework of GPR prospecting, the aim of this work is to compare the performances of a linear inverse scattering algorithm with respect to a "standard" GPR imaging procedure similar to reflection seismic processing. In particular, we will focus on two specific data interpretation techniques: the first technique is based on a 2D imaging procedure that consists in a sequence of data processing steps in time domain, whereas the second technique is based on a microwave tomography approach exploiting the Born approximation in frequency domain (Crocco & Soldovieri, 2003; Persico at al., 2005) The methods have been applied on both synthetic and experimental data collected in the Archaeological Park of Pontecagnano–Faiano, Southern Italy.

2 THE PROCESSING TECHNIQUES

The first technique consists in a processing ion the raw data to enhance the signal-to-noise ratio and to produce a more realistic image of the underground, and then a standard seismic processing made of:

- Zero time correction to equalize the propagation path of the signal within the cables and the antennas. The corrected signal takes into the propagation of the electromagnetic signal from the transmitting antenna to the structure and then to the receiving antenna.
- Background removal, performed by the subtraction of the average trace from the current trace.
- Suppression of multiple reflections. To this purpose, each multiple reflection is first flattened (this operation is based on the picked primary reflection) and then passed through an averaging filter.
- Kirchhoff 2D-velocity migration, which transforms the signal recorded in the time domain into a new spatially correct signal distribution, made up tracing back the scattered energy to its "source".
- Time-depth conversion.

The second technique belongs to the class of inverse scattering methods (Colton and R. Kress, 1992). In particular, in order to overcome the difficulty related to the non-linearity, the considered approach exploits the Born approximation (Colton and R. Kress, 1992). So, the inverse problem is formulated as the inversion of the linear integral equation:

$$E_s(f,\vec{r}_s) = \int\int_D G_e(f,\vec{r}_s,\vec{r}')E_{inc}(f,\vec{r}_s,\vec{r}')\chi(\vec{r}')d\vec{r}' \qquad r_s \in \Sigma \quad (1)$$

where f is the frequency, E_s is the scattered field (the configuration is multimonostatic, so that the source and observation points coincide), D is the investigation domain, E_{inc} is the incident electric field in D, G_e is the Green's function (Chew, 1995) and

$$\chi(\vec{r}_s) = \frac{\varepsilon(\vec{r}_s)}{\varepsilon_{bkg}} - 1 \qquad \vec{r} \in D \qquad (2)$$

is the function, being $\varepsilon(\vec{r})$ the (possibly complex) permittivity distribution in D and ε_{bkg} the background permittivity. The inverse scattering problem consists in solving eq. (1) to retrieve the contrast function (2) from the knowledge of the scattered field E_s. In particular, the linear integral relationship is discretized by means of MoM (Chew, 1995), and the problem is thus recast as the inversion of a linear algebraic system. However, equation (1) is a Fredholm integral of first kind [3], and so that the resulting linear system is ill-conditioned. As a consequence, the achieved solution may be unstable. Hence, only an approximation of the sought contrast can be reliably obtained. Such a "pseudo-solution" is obtained by making use of the SVD of the matrix that represents the discretized version of equation:

$$\tilde{\chi}(\vec{r}) = \sum_{n=1}^{N} \frac{1}{\sigma_n}\langle E_s, v_n \rangle u_n \qquad (3)$$

where σ_n are the singular values, v_n and u_n the singular vectors in the data and unknowns spaces, respectively; the index N is fixed on the basis of the signal-to-noise ratio.

3 RECONSTRUCTION ANALYSIS OF SYNTHETIC DATA

This section is focused on results from data simulated by means of the ReflexW 3.5 software [5], involving an iterative modelling procedure based on the exploding-reflector concept. The thickness and the geometrical characteristics of the synthetic scenario are relative to a half-space model (figure 1.a) with a high relative dielectric permittivity ($\varepsilon_r = 10$) and sized 2 × 2 m^2. Inside it, a wall with a different dielectric permittivity ($\varepsilon_r = 7$) is placed. The temporal and spatial sampling intervals are DT = 0.016 ns and DX = 0.02 m, respectively. The central frequency of the antenna is 400 MHz. This synthetic data set was processed by making use of the inverse scattering algorithm in the frequency domain. In particular, a work frequency band from 120 up to 540 MHz, sampled with a 30 MHz frequency step, was utilized. The spatial step of the data is 2 cm; the investigation domain D is 2 × 2 m^2, starting from the depth of 10 cm. The contrast has been expanded along a functional basis built up of 31 Fourier harmonics along the horizontal direction and 30 vertical steps. Figure 1.b represents the data after zero timing and background removal. Figure 1.c represents the data processed also by means of a 2D Kirchoff migration. Finally, figure 1.d represents the image obtained after the inverse scattering processing described above. As it can be seen, with respect to the 2D migration of fig. 2.c, in this case the size of the wall is more correctly retrieved and the multiple reflections under the focused hyperbola of fig. 1.c are not present.

4 RECONSTRUCTIONS ANALYSIS OF REAL DATA

In this section, we show some results obtained on a real dataset gathered at the archaeological site of Pontecagnano (SA). The GPR survey was carried out with a GPR SIR System-3000 with a 400 MHz central frequency antenna operating in a continuous mode, near archaeological excavations.

The survey was concerning the shallow layers within a few meters below the measurement surface. Since the underground terrain is made by pyroclastic material interspersed with limestone, we can estimate about 9-11 cm/ns for the electromagnetic wave velocity corresponding to a probing wavelength of 22 up to 27 cm.

Four profiles were considered, 20 m long and 0.5 m spaced.

Figures 2 and 3 show the source reconstructions for the second profile, by using the two different approaches. Time domain processed data with zero-time correction and background removal is shown in Figure 2. This time, the correction for multiple reflections reduction is not necessary since multiple reflections do not appear in the considered time window. The acquisition parameters are shown in table 1.

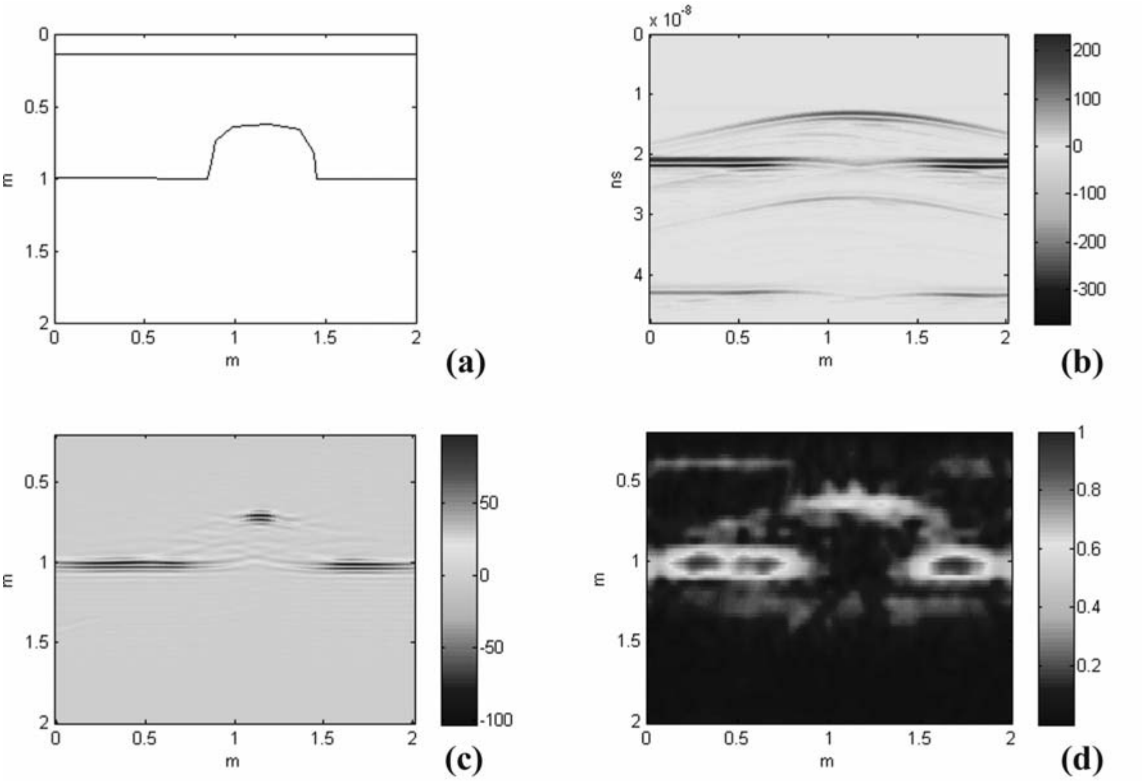


Figure 1 / Syntethic data: model (a), Time domain processed data: zero-time correction, background removal filter (b), Time domain processed data: zero-time correction, background removal filter multiple removal and after Kirchhoff 2D-velocity migration (c). Inverse scattering processing of time domain processed data with zero time correction and background removal filter(d).

Mode	Time
Samples	512
Rate (scan/s)	64
Gain (dB)	-13, -13, 39, 39, 40
Range (ns)	50

Table 1 /Acquisition parameters.

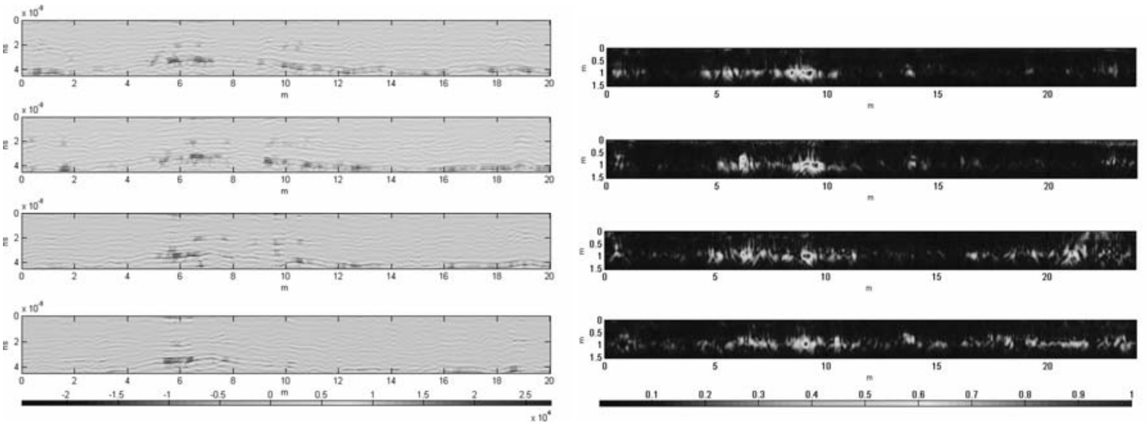
The inverse scattering image depicts the modulus of the complex contrast function that gives information about the position and the extent of the anomalies. We used, to achieve this inversion result, a threshold based on the behaviour of the singular values. In other words, we have see that at a certain point there were a meaningful change of the slope of the “curve”, and we have put the threshold at that kneel. This has lead to retain 450 singular values for the inversion.

In this case it can be seen that both methods of processing put into evidence the presence of structures persistent through different profiles. Looking at the tomographic reconstructions (figure 3) we may observe the reconstructed anomalies positioned between the abscissas 5 and 10 m. In particular, we can see a sharp contrast in all the profiles around x=8 m and another one about x=13 m. Their depth is approximately 0.9 m, about 0.2 m deeper than the structures visible in the archaeological essays.

5 CONCLUSION

In this paper we described the application of a standard time domain GPR processing and an inverse scattering procedure to synthetic and experimental GPR data gathered at Pontecagnano (SA). The inverse scattering approach exploits a consistent, although simplified, model of the electromagnetic scattering. It is worth noting that there are several strong assumptions underlying the inverse model adopted here. For instance, we assumed a half-space as the background scenario; this entailed the necessity of pre-processing procedures to adapt the data, actually collected in a layered scenario, to the inversion scheme.

With regard to the computational cost of the inverse scattering algorithm, the offline construction of each matrix required about five hours on a PC and the calculation of its SVD required about five minutes. Afterwards, the inversion by itself is a real-time procedure. Conversely, the Reflex processing does not require offline calculations and, substantially, it is entirely performed in real time.



Figures 2/3. (Left) Time-domain processed real data: zero time and background removal. (Right) Inverse scattering processing of time-domain processed real data with zero-time and background removalfilter.

As a final comment, it can be said that the inverse scattering technique, with respect to the standard GPR procedure of processing, implicitly contains a focalization procedure and allows us to adopt regularization schemes that make the inversion potentially more robust against noise and parametric uncertainties. Therefore, this technique appears to be extremely significant as a support to the experience of the human operator. In particular, even if this experience keeps essential for the interpretation of raw data, it can be meaningfully helped by the availability of reliable and more easily interpretable images. On the other hand, it has to be said that, due the complexity of the scenario usually dealt with, one cannot completely rely on a single processing approach. Accordingly, multi-sensor and multi-processing approaches can be exploited in order to further help the operator through the comparison of the results arising from different techniques.

6 REFERENCES

Crocco, L., Soldovieri, F. 2003. GPR prospecting in alayered medium via microwave tomography, *Annals of Geophysics*, 46 (3) : 559-572.

Persico, R., Bernini, R., Soldovieri, F. 2005. On the configuration of the measurements in inverse scattering from buried objects under the distorted Born approximation, *IEEE Trans. On Antennas and Prop.*, 53 (6) : 1875-1886.

Colton, D., Kress, R. 1992. *Inverse acoustic and electromagnetic scattering theory* , Berlin: Springer Verlag.

Chew, W.C. 1995. *Waves and Fields in inhomogeneous media*, Piscataway, NJ: Institute of Electrical and Electronica1 Engineers,.

Sandmeier, K. J. 2005. *Manual Scientific Software-ReflexW 3.5*, ZipserStrabe 1, Germany.

Analysing the velocity of ground-penetrating radar waves: a case study from Koekelare (Belgium)

L. Verdonck[1], D. Simpson[2], W. Cornelis[2], A. Plyson[3], J. Bourgeois[3]

1 Dept. of Archaeology and Ancient History of Europe, Ghent University, Blandijnberg 2, 9000 Ghent, Belgium, email: Lieven.Verdonck@UGent.be

2 Dept. of Soil Management and Soil Care, Ghent University, Coupure links 653, 9000 Ghent, Belgium, email: David.Simpson@UGent.be, Wim.Cornelis@UGent.be

3 Dept. of Archaeology and Ancient History of Europe, Ghent University, Blandijnberg 2, 9000 Ghent, Belgium,

Email: Annebeth.Plyson@UGent.be, Jean.Bourgeois@UGent.be

Keywords: GPR, velocity analysis, Bronze Age burial mounds, TDR, augering

ABSTRACT: When conducting a ground-penetrating radar (GPR) survey, initially only the two-way travel time of the electromagnetic waves is available. Knowing the propagation velocity of the waves in the ground is crucial for determining the depth of the archaeological features. There are several ways to determine the velocity. Four methods were compared at the site of Koekelare (Belgium).

Geophysical surveys with different instruments were carried out over a double and a single circular ditch, originally belonging to Bronze Age barrows. A survey with a fluxgate gradiometer and electromagnetic induction measurements did not reveal the structures or only partially. In the GPR measurements both structures were clearly visible.

For the velocity determination, time-domain reflectometry (TDR) measurements were taken, which were compared with two techniques, based on the presence of diffraction hyperbolas in the GPR data (hyperbola fitting and migration).

The wave velocities obtained with the three methods mostly matched rather well, the average velocity varyied between 0.069 and 0.074 m/ns. The velocities were then used for the time-to-depth conversion. In most cases reflections were detected by the GPR at a greater depth than suggested by the augering results. This discrepancy merits further investigation.

1 INTRODUCTION

Since the beginning of the 1980s, the remains of over one thousand Bronze Age burial mounds have been discovered by aerial photography in the provinces of East- and West-Flanders (Belgium). These monuments belong to the Early and Middle Bronze Age (2000-1500 BC). Mostly, circular ditches are the only remnants of the monuments. The mounds themselves have not been preserved as a result of erosion and agricultural activity. The ditches have been filled up but remain visible as cropmarks on the mainly sandy soils. On some sites, augerings and excavations have been carried out (for a recent example: Cherretté & Bourgeois 2005).

The aim of the present study was to investigate the potential of geophysical techniques for the detection of the circular monuments, and for the estimation of their depth. The study area was part of a 500 by 225 m large cemetery, consisting of at least 9 circular structures, including two double circles. It is situated in Koekelare-Boutikel, West-Flanders (figure 1), at the foot of the slightly undulating plateau of Aartrijke-Wijnendale. The site was discovered through aerial photography by pilot J. Semey in August 1990 (figure 1). One single and one double circle were selected for the geophysical survey.

2 METHODOLOGY

Over the double ditch, prospections were carried out with several instruments in an area of 50 by 50 m. To define the corner points, a differential GPS was used. A survey with a Geoscan FM256 fluxgate gradiometer did not reveal the structures, as probably the contrast in magnetisation between the ditch and the surrounding soil was too small. Electromagnetic induction measurements (conductivity and magnetic susceptibility) with a Dualem instrument gave similar results. Conductivity measurements with a Geonics EM38DD were able to reveal parts of the inner and outer ditch, although not very clearly. The GPR measurements (taken with a Sensors & Software pulseEKKO PRO) clearly revealed both ditches. Subsequently, the single circle was also investigated with the GPR.

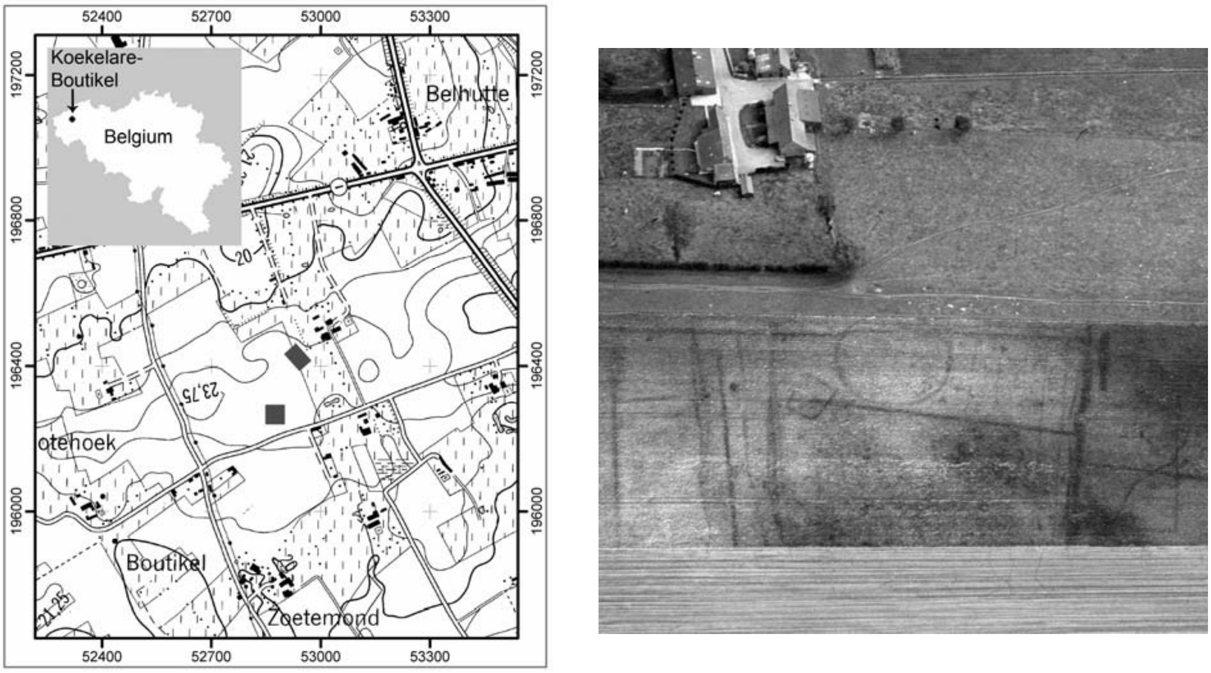


Figure 1. (left) Location of the site, with indication of the grids used for the investigation of the double (southern) and single (northern) circles; (right) Aerial photograph of the single circle with next to it a smaller rectangular structure (photo J. Semey, No. 60615).

With the GPR, a 500 MHz antenna was used. Measurements were taken with an inline distance of 0.05 m, the line separation was 0.25 m, the sampling interval was 0.2 ns. Processing included application of a dewow-filter, a fixed gain and a band-pass filter with cut-off frequencies of 150 and 600 MHz. No topographical corrections were made since the terrain is virtually flat.

For the depth estimation, several techniques were applied (for a discussion of the methods for velocity and depth determination, see e.g. Conyers 2004). Two GPR data processing methods (migration and hyperbola fitting) rely on the presence of diffraction hyperbolas in the data. The hyperbolas are caused by the radiation pattern of the GPR antenna, which emits energy in a cone and not along a straight line. A range of velocities was used as input for a Kirchhoff migration algorithm until the best result was obtained, i.e. until the hyperbola tails were collapsed without any over-migrated reflectors ('smiles') appearing. In hyperbola fitting, computer-generated hyperbolas with known velocities are fitted to hyperbolas in the measured GPR profile until the right velocity is found.

Furthermore, time-domain reflectometry (TDR) measurements were carried out over the double ditch with a Campbell Scientific TDR100 instrument. The principles behind TDR are similar to GPR. TDR sends electromagnetic waves into the ground via metal rods. At the extremity of the rods, the signal is reflected. Since both the length of the metal rods (at Koekelare these were 0.23 m long) and the travel time are known, the velocity of the pulses can be calculated (Leckebusch 2003). The TDR measurements were taken at different depths, with intervals of 0.2 m, which resulted in a series of vertical velocity profiles.

The GPR and TDR measurements were compared with augerings. Different hand augers were used: a half-cylindrical gouge auger with a diameter of 0.03 m and a length of 1.3 m and an Edelman auger with a diameter of 0.05 m and a length of 0.2 m, which reached a depth of 1.2 m. For the TDR measurements, a Riverside auger was used.

3 RESULTS AND INTERPRETATION

3.1 *General remarks*

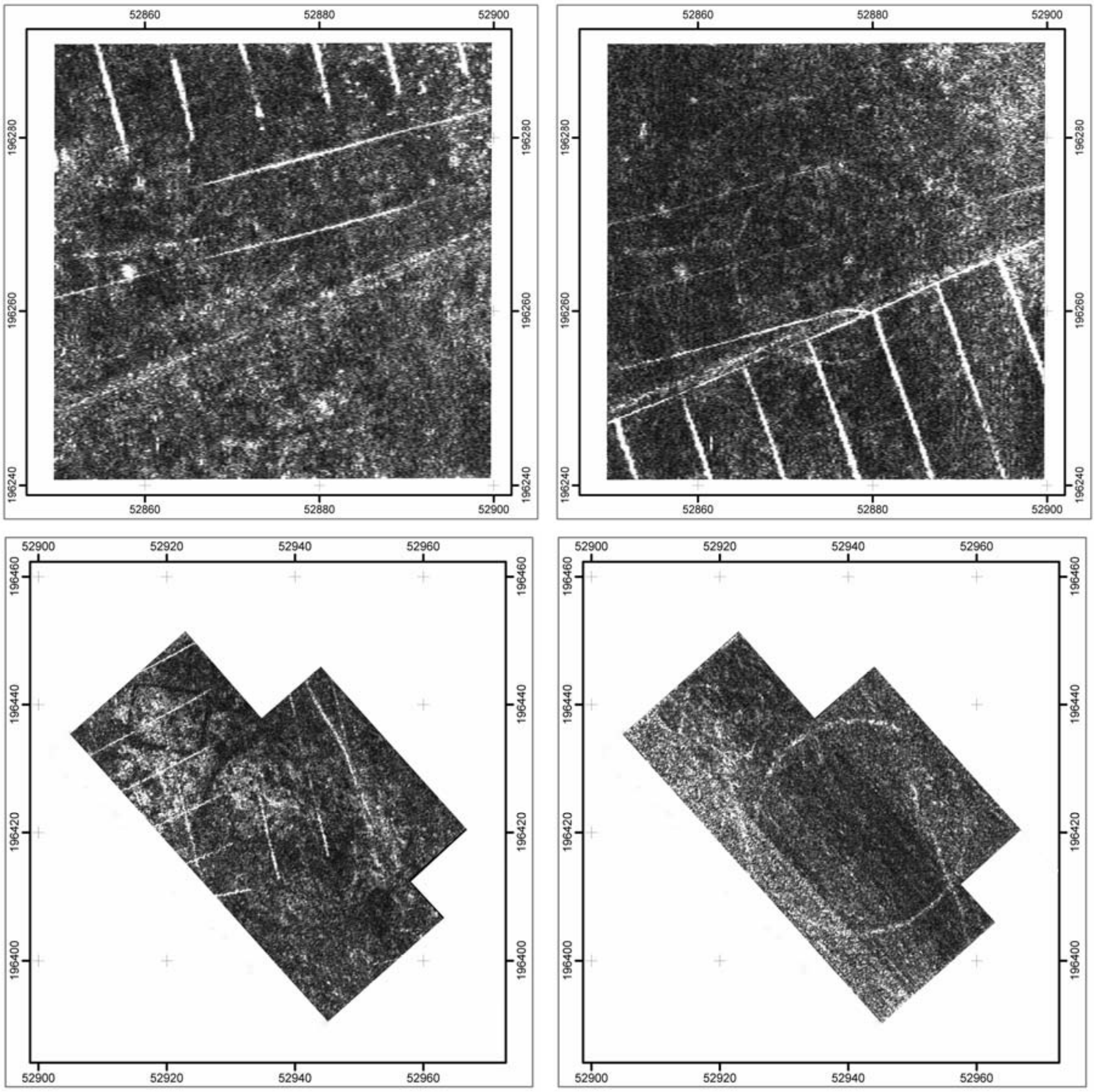


Figure 2. (top left) GPR depth slice 0.67-0.75 m; (top right) depth slice 0.97-1.05 m (double circle); (bottom left) depth slice 0.67-0.75 m; (bottom right) depth slice 1.11-1.18 m (single circle). White represents a strong GPR reflection, black a weak reflection or the absence of reflections.

The most striking features on the GPR depth-slices shown in figure 2 are a series of parallel drains in brick, causing strong reflections at different depths. The traces of the circular ditches are much more subtle. Remarkably, they are visible as a negative mark (absence of reflections) from 0.5 m to 0.75 m below the surface. Probably this is because the ditches have been dug into a soil which is more reflective, for example because of accumulation horizons of iron or clay (Podzols, mostly occurring in degraded form: Postpodzols), than the loose ditch fill. Only the inner circle of the double ditch does not show as a negative mark.

At deeper levels, the ditches were detected as a positive mark (from around 0.8 to 1.25 m below the surface). That the ditches are visible down to a considerable depth can be explained by the soil type causing a low attenuation of the radar waves. On the soil map, the area of both circles is described as ‘moderately dry loamy sand on a sandy-clayey substratum’.

The double ditch structure is rather large in size: the diameter of its outer circle is nearly 40 m, whereas the average size of the monuments with concentric circles is about 30 m. The diameter of the inner circle is 22 m. The single circle has a diameter of 33.5 m. The majority of the single structures in East- and West-Flanders have a diameter between 20 and 35 m (Ampe *et al.* 1996). There are no visible interruptions of the ditches. At a depth of around 0.85 m, the ditches are around 0.7 m wide. Near the single circle, a rectangular feature of *ca.* 8.5 by 12 m can be observed, which is also clearly visible on the aerial photographs (figure 1). Most probably, it belongs to the Iron Age. Often, Bronze Age cemeteries continued into the Iron Age or the Roman period (Bourgeois *et al.* 1998).

3.2 *Depth estimation*

The drainpipes caused strong hyperbolas in the GPR profiles, which facilitated the application of hyperbola fitting and migration. For the double monument, a velocity of 0.069 m/ns proved the most correct for hyperbola removal and was used for the time to depth conversion. For the single circle, the appropriate velocity was slightly higher, around 0.074 m/ns. Since both structures were surveyed with an interval of nearly 3 weeks, a change in soil conditions may explain this difference. There was little variation in the velocity within the lines or between the lines. Most drainpipes occur at a depth of 0.7 m to 1.10 m. At other depths, few hyperbolas were available for migration or hyperbola fitting. As the ditches mainly occur at this depth, the velocity in the deeper levels was of less importance and the velocities obtained in shallower levels were also used there.

The velocity obtained for the double circle corresponded well with the results of the TDR measurements. On average, the velocity was around 0.08 m/ns in the shallowest layers, around 0.07 m/ns from 0.6 to 1 m below the surface, and less than 0.07 m/ns in the layers below 1 m. Perhaps surprisingly, there were no big differences in the water content (and the velocity) between the ditch and the surrounding soil.

The depth estimation based on these velocities shows reflections (positive, white marks in figure 2) at a depth of 0.8 to 1.25 m, as described earlier. From excavations, it is known that the ditches are on average 1 to 1.5 m deep. Often the filling of the ditches consists of three layers: on the bottom rests a small humus enriched layer, which accumulated when the ditch was still in use. On top of this, yellow sandy material can be observed, probably originating from the mound and suggesting a fast filling of the ditch when it was no longer in use. After a stabilization phase, the final filling consists of a dark layer, rich in humus (Ampe et al. 1996). Possibly, the reflections observed in the GPR results are caused by the transition between the lower, humus enriched layer and the original soil. However, in most cases the results of the augering seem to contradict the presence of such a humus layer below 0.85 m.

4 CONCLUSION

At the site of Koekelare, the loamy sandy soils and the corresponding low attenuation of GPR waves allowed the detection of several circular ditches, belonging to Bronze Age funeral monuments. TDR measurements, as well as methods based on the analysis of the GPR data themselves (migration) resulted in a consistent velocity determination. The deepest reflections visible on the GPR depth slices are not entirely confirmed by the results of the augering. They may also be caused by soil processes. This point merits further investigation.

5 REFERENCES

Ampe, C., Bourgeois, J., Crombé, P., Fockedey, L., Langohr, R., Meganck, M., Semey, J., Van Strydonck, M., Verlaeckt, K. 1996. The circular view: aerial photography and the discovery of Bronze Age funerary monuments in East- and West-Flanders (Belgium), *Germania*, 74: 45-94.

Bourgeois, J., Meganck, M., Semey, J. 1998. *Cirkels in het land: een inventaris van cirkelvormige structuren in de provincies Oost- en West-Vlaanderen II. Gent*, Archeologisch Inventaris Vlaanderen VZW (= Archeologisch Inventaris Vlaanderen, Buitengewone reeks, 5).

Cherretté, B., Bourgeois, J. 2005. Circles for the dead. From aerial photography to excavation of a Bronze Age cemetary in Oedelem (West-Flanders, Belgium), in Bourgeois, J., Meganck, M., *Aerial photography and archaeology 2003: a century of information*, Gent, Academia Press, 255-265.

Conyers, L.B. 2004. *Ground penetrating radar for archaeology*, Walnut Creek, Altamira Press.

Leckebusch, J. 2001. *Die Anwendung des Bodenradars (GPR) in der archäologischen Prospektion: 3D-Visualisierung und Interpretation*, Rahden, Verlag Marie Leidorf GmbH.

Preservation of archaeological patrimony through georadar study. The case of the Historical Center of the Merida City, Yucatán, Mexico

L. Barba[1], J. Ligorred[2], J. Blancas[1], A. Ortiz[1]

1 Instituto de Investigaciones Antropológicas (IIA) of the Universidad Nacional Autónoma de México, e_mail: lubarbapin@gmail.com

2 Departamento de Patrimonio Arqueológico y Natural del Municipio (DPANM) del Ayuntamiento de Mérida, e_mail: jligorred@gmail.com

ABSTRACT

This paper shows the results of the georadar archaeological prospection carried out by the Laboratorio de Prospección Arqueológica from the Instituto de Investigaciones Antropológicas (IIA) of the Universidad Nacional Autónoma de México (UNAM) verifing the archaeological and historical information recovered by the Departamento de Patrimonio Arqueológico y Natural del Municipio (DPANM) del Ayuntamiento de Mérida en el Centro Histórico de la Ciudad de Mérida as a part of a joint academic research project.

The Historical Center of Merida has been classified as a “zone of high patrimonial value” after the topographic data and the historical documents recovered showed a long-term occupation, non interrupted since pre-Columbian times, when T’Hó was the great capital of the northern region of the Maya area.

For the government rehabilitation program of the Historical Center of Merida, it has been a great priority to verify the existence of archaeological remains -pre-Columbian or colonial- under the present streets, gardens and plazas that could be damaged during the public infrastructure works. In order to prevent any damage to the patrimony a large georadar study was carried out pulling 200 and 400 MHz antennas of the GSSI SIR System 2 for 16,500 m of the city streets.

After data analysis, it was possible to build up a large map with the location of the most noticeable archaeological remains under the pavement of the streets that confirmed many of the topographic and documental proposed archaeological platforms. As a final result, by the first time a city government of Mexico has available information to take decisions to update urban infrastructure, while preventing the damage to the archaeological patrimony of the lost Maya city.

1. INTRODUCTION

One way of studying a city evolution is through the remains of the past, the recovering of the memory and through the interpretation of the ancient human occupation evidence. Under that perspective Archaeology look at the subconscious of the city, searching for the original land that was transformed into a social group home, and reconstructs the spaces and activities carried out there by the ancient people. All these ideas come through with the integration of the archaeological patrimony to the new public spaces of the city promoting their use, the communal appropriation and its social value (Ligorred 2008).

The Historical Center of Merida has been classified as a "zone of high patrimonial value" based on the topographic data and the historical documents analyzed showing a long-term occupation, non-interrupted since pre-Columbian times, when T’Ho was the great capital of the northern region of the Maya area. For the rehabilitation program of the Historical Center it has been a great priority to verify the existence of archaeological remains, pre-Columbian or colonial, under the modern streets, gardens and plazas that could be damaged during the public infrastructure works.

In order to prevent any damage to the patrimony a large georadar study was carried out pulling 200 and 400 MHz antennas of the GSSI SIR System 2 for more than 16500 m of the city streets, focusing in the areas where infrastructure works were imminent. After the analysis of the radar data it was possible to build up a map with the location of the most feasible archaeological remains under the pavement of the streets that confirmed many of the structures suggested by topographic and documental analysis.

2. THE STUDY AREA

After the first approach studying ancient maps (granted by FAMSI) it was stated that the present Historic Downtown of Merida, in all probability was built over the ancient T’Hó that was settled on a large natural terrain elevation (contour line 4). Above this there were found some spots with higher elevation (contour lines 5 and 6) that seem to have been chosen by Mayans to build the structures that once formed that human settlement known as “Noh Cah Ti Hoo” (the great town of T’Hó).

In the surroundings of the central area, under the contour line 4, it can be observed a large amount of depressions or excavated areas likely produced by the quarry of building materials, and perhaps also used as water deposits.

Basis on the analysis of the topographic maps, the historic documentation and the supervision of street infrastructure works during last years, 16 priority areas with high archaeological potential were established. A new protection program was justified and developed in order to prevent the damage to the underground archaeological patrimony as a consequence of the installation of new cables and pipes in the oldest part of the city.

Taking into consideration previous information, it was possible to produce a map with the proposed zones in downtown area where the structures of the Maya city of T'Hó could be placed. The next step was to put together a joint academic project that included a georadar survey to verify the location of proposed structures. Besides the archaeological remains some geophysical anomalies could be produced by modern materials like pipes, some other by early colonial remains and last, some geological discontinuities could produce local responses.

3. OBJECTIVES

The actions included in this joint project were carried out to prevent any damage to the archaeological patrimony of the downton Merida City during the forthcoming infrastructure works.
Georadar survey was chosen to test the archaeological areas marked in the city map to: (i) locate the archaeological remains; (ii) verify the sacbés remains that might connect T'Hó with Caucel or Xoclan; detect the karstic zones associated to caves and cenotes

4. METHODOLOGY

The employed methodology included two steps: the archaeological prospection was the first. In all cases detected anomalies were represented by radargrams or through depth slice maps processed in computer just after survey to get a constant feedback.

After interpreting the survey results, it was advisable to verify the presence of archaeological remains before they could be damaged during the electric infrastructure works. The few architectural structures found during these works were consolidated according to international standards and their building system.

Taking into consideration the high probability of finding remains of major structures, it will be necessary to get INAH permissions to proceed with further archaeological excavations.

5. GEOPHYSICAL SURVEY

Through the use of georadar the Archaeological Prospection Lab carried out the study of archaeological remains that have been covered by urban development. This study was carried out in all places suggested by previous cartographic analysis and by the hypothesis established by Josep Ligorred from Departamento de Patrimonio Arqueológico y Natural del Municipio (DPANM).

During this part of the project 127 georadar continuous profiles, with 80 and 160 ns windows and a total lenght of 16,584 meter were taken during the nights of two weeks of urban field work.

6. RESULTS

Results from the application of this geophysical technique on the streets of Merida city, revealed anomalies from natural and cultural origin. Some of them suggest the presence of buried archaeological remains while others look like closer to geological origin.

Many georadar profiles show continuous horizontal reflections that have been interpreted as the leveled surface where archaeological structures were built because most of them have a close correlation with the higher elevation areas established by previous cartographic studies.

Georadar survey allowed the detection of more than one hundred anomalies (table 1) related with archaeological structures –leveling surfaces and walls-, defensive colonial walls, and depressions and cavities probably associated with cenotes. Lines below we present some results that will be the basis to plan future detailed geophysical studies and punctual excavations to verify prehispanic and colonial remains.

6.1 External Northwestern Sector, Sacbés (old Mayan streets)

Radargrams of the lines F57 and F58, acquired on Street 74, show reflections with characteristics such as amplitude, dimensions and morphology that were identified as sacbés in previous experiences in the zone. In addition, we found some other anomalies interpreted as modern trenches and small natural cavities.

6.2 Northeast Sector

Line F61, show a strong reflection block from 2 to 24 m that includes an urban infrastructure area from 6 to 12 m found at 1.5 m depth. A bit further, there is a sharp discontinuity and then the reflection reappears form 35 to 73 m. It is again interrupted and continues from 77 to 148 m when the radar antenna reached the street 62. These described horizontal reflections are closely related with the large pink area marked in the map.

Line F63 shows a clear horizontal reflection from 1 to 73 m of the antenna path to a 1 m depth. There is some change in the reflective pattern going deeper until 1.6 m where it is possible to observe modern urban features. Again, these anomalies are closely related to another pink zone marked as elevated in the downtown area map.

6.3 Cathedral graves

As a result of the georadar survey in lines F117 to F127 it can be observed various hyperbolic reflections. Because all of them are located in the street in the North side of the Cathedral, they have been interpreted as colonial time graves.

6.4 Northeast Sector (Parque de Mejorada)

In the parque Mejorada we chose two lines that have reflections associated with the presence of architectural remains. In this case the horizontal reflections are deeper that other studied places but share the same characteristics. As in many other cases during this survey we observed large amounts of iron pipes under the streets.

In this line F14? we observed large amplitude reflections interpreted as cavities and fractures of the parent rock. From 55 to 63 m of the antenna path there are clear horizontal reflections directly related to another elevation zone marked in the map.

In line F28 it is noticeable a group of continuous horizontal reflections from 4 to 72 m that corresponds to another zone in the map, in addition to a wall excavated between 63 and 63A streets.

6.5 Wall verification on street C58 between 63 y 63 A

This is a detailed grid to track the tendency of a wall found during the excavation of a pit in the street. Grid was set following the small visible portion of the wall and included all the available area across of the street. In the time slices, it is obvious the path of the wall in the Eastern limit of the map. In addition it is possible to recognize two other linear marks. One was the limit of the sidewalk, while the other a modern trench for urban infrastructure. In 0.5 m depth slice it can be seen the limit of the sidewalk. Down to 0.7 m a trench with pipes and cables can be clearly observed. Even deeper from 1 to 1.3 m we found the thick stone wall excavated in this area.

6.6 Southwest Sector

Line F76, presents a large amount of shallow reflections related with modern cover materials and urban works. The most outstanding anomaly is placed between 52 to 74 m at 0.7 m depth and have a direct relationship with one of the registered elevation zones.

6.7 Southeast Sector

Along the street 67A we have the path of the line F19 with a reflections that show the presence of small cavities and fractures of the parent rock that suggest the presence in this public park of one of the cenotes that oral urban traditions talk about. Close to the cross with street 67, from 67 to 308 m, we also have a horizontal reflection in close relationship with one of the elevated areas marked in the map.

6.8 Wall in street 65

In this case a pit for urban infrastructure works was excavated and found a small portion of a wall. Then the grid was settled down to verify if this wall could reach the other end of the street. One meter time slice shows two red paths. One corresponds to the wall we were following, but the other shows the track of the trench with electric wires inside plastic pipes.

7. FINAL COMMENTS

Working under a joint agreement the Laboratorio de Prospección Arqueológica from the Instituto de Investigaciones Antropológicas (IIA) of the Universidad Nacional Autónoma de México (UNAM) verified the archaeological and historical information recovered by the Departamento de Patrimonio Arqueológico y Natural del Municipio (DPANM) del Ayuntamiento de Mérida en el Centro Histórico de la Ciudad de Merida.

Most of the radargrams detect the parent rock contact between 1.5 and 2 m showing a slight change in the texture. Above this contact it was common to find accumulations of clayish sediments that produced absorption of the electromagnetic waves.

The most important cultural remains are identified by strong horizontal and continuous reflections around 1 m depth. Sometimes it was possible to see well-defined limits. They have been interpreted as cultural leveled surfaces above which ancient structures were built.

In some other cases it was possible to recognize some deeper reflections that go beyond the contact with the parent rock. In this case, they have been interpreted as fractures and discontinuities in the limestone parent rock, producing a karstic zone possibly related to underground cenotes.

As a final result, a map including all the radar anomalies found was produced, and by the first time in Mexico, the Merida city government has available information to make decisions concerning modern urban development, while preventing the damage to the archaeological patrimony of the city.

Exploitation of a microwave tomographic approach for GPR data processing collected at historical buildings of Chania (Crete, Greece).

M. Bavusi[1], S. Piscitelli[1], F. Soldovieri[2], L. Crocco[2], G. Prisco[2], F. Vallianatos[3]

1 Institute of Methodologies of Environmental Analisys (IMAA)/Laboratory of Applied Geophysics, National Research Council, Tito Scalo (PZ),85100, Italy. E-mail: bavusi@imaa.cnr.it; piscitelli@imaa.cnr.it.

2 Institute for Electromagnetic Sensing of the Environment (IREA), National Research Council, Via Diocleziano 328, 80124 Napoli, Italy. E-mail: soldovieri.f@irea.cnr.it, crocco.l@irea.cnr.it.

3 Technological Institute of Creete Laboratory of Geophysics & Seismology Department of Natural Resources & Environment - 3 Romanou, 73133, Chalepa, Chania, Crete – Greece. E-mail: fvallian@chania.teicrete.gr.

Keywords: GPR prospecting, processing techniques, fracture detection, microwave tomography

ABSTRACT

In this paper a high frequency (1.5 GHz) GPR survey has been performed at two important historical buildings of the Chania City (Crete, Greece) such as the Venizelos's House and the Prefecture of Chania. The aim of the survey was to investigate the floors and the walls exhibiting surface fracture evidences. In this framework, GPR technique can provide an adequate spatial resolution when a proper data processing is exploited. In this work a three-stage classical time-domain approach processing, made up of pre-processing, filtering and one-dimensional velocity model migration, has been performed on the acquired data. Moreover, a novel frequency-domain processing approach based on the microwave tomography under Born approximation has been exploited, firstly replacing only the migration and then filtering stage also. The comparison between the two techniques showed that the microwave tomography provides more detailed images and improves the horizontal resolution in both cases. This suggests that microwave tomography can be a reliable complete processing tool requiring only the definition of the reference scenario, i.e., the dielectric permittivity and the conductivity of the host medium (soil, floor, wall).

1 INTRODUCTION

A GPR survey has been performed at two important historical buildings of the Chania City (Crete, Greece), see figure 1a, such as the Venizelos's House and Prefecture of Chania with the aim to investigating the fracture affecting floors and walls. The fractures can represent the effects of the dynamic behavior of the building under a seismic action and can, in they turn, affect the structural behavior of the building. Thus, their investigation can reveal important building structural defects and help to plan restoration project.

A fracture can be detected only when a valuable contrast of the physical properties arises, and this occurs if the fracture is filled by air or a material different from the host medium. Moreover, a fracture is generally orthogonal to the plan of the survey surface and therefore a good horizontal resolution is needed to localize it (Tsoflias *et al.*, 2004).

In this framework, Ground Penetrating Radar (GPR) technique provides the adequate spatial resolution when a frequency range from 1000 to 2000 MHz is exploited, but a fundamental role is played by the data processing to exploit all the allowable spatial resolution (Grandjean & Gourry, 1996).

In this paper, we deal with the possibility of implementing a novel microwave tomography inversion algorithm under the Born Approximation (BA) in the framework of a standard processing routine (Soldovieri *et al.*, 2007). This approach permits us to obtain an image of the structure in terms of the contrast function (accounting for the difference between the electromagnetic properties of the targets and the ones of the host medium) in an automatic way by recasting data processing as an inverse scattering problem (Soldovieri *et al.*, 2006; Soldovieri *et al.*, 2007).

In particular, all collected datasets have been processed by a classical time-domain processing routine made up of three stages: pre-processing, needed to obtaining a geometrically well-defined data grid; filtering, to enhancing signal/noise ratio; one-dimensional model based Kirchoff migration to collapse the hyperbolas and correcting the other reflector geometries. Then, microwave tomography was carried out in data processing, just as a replacement of migration and then on both not-filtered not-migrated datasets to evaluate the ability of the novel algorithm in the inverting a merely pre-processed data.

The results comparison showed how, starting from a pre-processed filtered data, microwave tomography provides more detailed images and improves the horizontal resolution compared to the one-dimensional velocity model based Kirchoff migration result. Furthermore, the microwave tomography performed on a merely pre-processed data showed a result as much good as its application on a pre-processed and filtered data. This suggests microwave tomography can be a reliable complete processing tool requiring only the definition of the reference scenario, i.e., the dielectric permittivity and the conductivity of the host medium (soil, floor, wall).

2 DATA ACQUISITION

A number of high frequency GPR survey lines have been acquired in the Venizelos' house and in the Prefecture of Chania building.

The Venizelos' house is the place where the revolutionary patriot Eleftherios Venizelos (1864-1836), prime minister and the "maker of the modern Greece", lived. This edifice, which now is a museum and holds an enormous historical and symbolic value for the Greece, shows fractures in its walls made up of cemented irregular stones.

The second building is the headquarters of Prefecture of Chania, an ancient edifice with a quadrangular shape in plan view consisting of four office buildings 60 m long of two or three floors linked at right angle to form an internal courtyard. This edifice exhibit some fractures in the floors.

For sake of brevity a survey line, 0.80 m long carried out on a wall of Venizelos' house (figure 1b) and a fracture 2 m long in a floor of Prefecture of Chania building (figure 1c) will be discussed. In both cases the fractures fall at the center of the survey line corresponding at 0.40 m for Venizelos' house survey and 1.0 m for the Prefecture. The radargrams have been acquired by using the GSSI system with the SIR2000 control unit and a 1,5 GHz antenna set; in the survey we exploited a scan rate of 32 scans/second, 512 samples/scans and a 16 bit sampling.

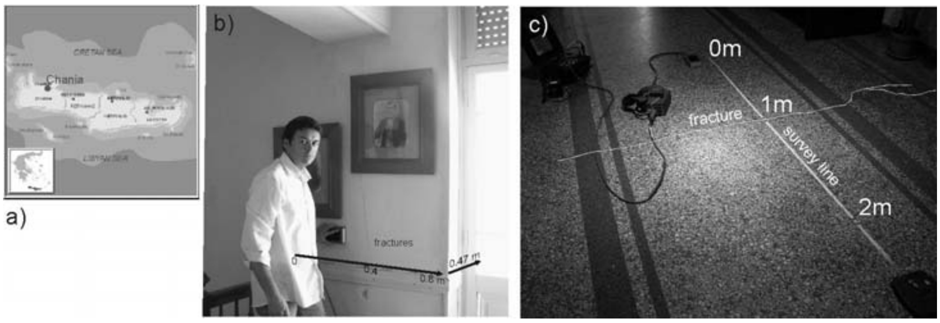


Figure 1. a) Crete island map; b) 0.8m long survey line out on a wall of Venizelos' house; c) 2m survey line carried out on a floor ov Prefecture of Chania building.

3 DATA PROCESSING AND RESULTS

3.1 *Classical Processing*

All data sets have been processed with a classical time domain processing routine consisting of three stages: pre-processing, filtering and migration. Pre-processing consisted of a geometrical regularization of radargrams obtained through *trace removal*, *trace normalization*, *zero time correction* and *time cut*. Basically, a pre-processed data is a geometrically correct raw data. An example of a pre-processed radargram of Venizelos' house is shown in figure 2a.

Filtering stage included several 1D and 2D filters (*frequency filtering, subtracting average and fk filtering, etc.*) needed to enhance the signal/noise ratio.

Finally, *migration* has been based on a one-dimensional velocity model. For Venizelos' house a velocity of 0.125 m/ns has been calculated by dividing the double wall thickness (0.47 m) for the single time corresponding to the outside wall reflection (3.75 ns). For Prefecture of Chania building, velocity has been provided by the hyperbola adaptation. Figure 2b shows pre-processed filtered and migrated radargram acquired in the Venizelos' house in terms of normalized absolute value of the amplitude. Several vertical reflections, related probably to the inner structure of the wall, can be seen, but any fracture evidence has been detected near the fracture zone.

3.2 *Microwave tomography approach*

Alternatively, migration has been replaced by microwave tomography under BA assumption in the third stage (figure 2c).

Microwave tomography solves an inverse scattering problem that amounts to determining the unknown contrast function from the knowledge (measurements) of the scattered field in frequency domain Soldovieri *et al.*, 2006; Soldovieri *et al.*, 2007). The scattered field is given as the "difference" between the total field and the unperturbed field. The total field is the field reflected by the soil when the buried objects are present. The unperturbed field is the field reflected by the soil when the objects are absent and, therefore, accounts for the reflection/transmission at the air/soil interface. The 'unknown' of the inversion problem is the contrast function, which accounts for the difference between the dielectric permittivity and electrical conductivity of the objects and those of the soil. The result of the reconstruction is a spatial map of the modulus of the contrast function within the investigated region. The zones where the modulus of the contrast function is significant provide the necessary information about the presence, location and extent of the buried objects.

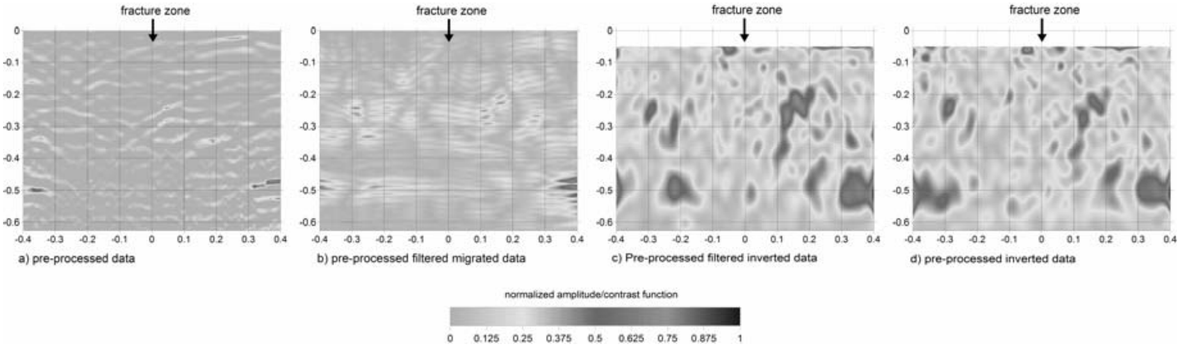


Figure 2. Radargram corresponding to the survey line of fig. 1b carried out in the Venizelos' house. In the fracture zone the fracture parts in to branches. a) pre-processed (raw) data; b) time domain full processed data; c) microwave tomography carried out on the pre-processed filtered data; d) microwave tomography carried out on the merely pre-processed data.

Microwave tomography investigated a domain between 0.05m and 0.625 m. The inversion procedure highlighted several anomalous zones related to the inhomogeneous structure of the wall, but in the fracture zone two vertical structures well correspond to two branches of the fracture outcropping in this zone. Moreover, the two vertical structures seem not interest all the thickness of the wall.

Finally, we evaluated the possibility of replacing both second and third stage of the classical processing with the microwave tomography; thus, the tomographic approach was applied directly on the pre-processed data of figure 2a. The reconstruction result is depicted in figure 2d and is very similar to the previous one of figure 2c, indicating the microwave tomography can applied on a not-filtered data set.

Finally, Prefecture of Chania building data set has been processed starting directly by the pre-processed data (figure 3b). In this case the improvement of spatial resolution and of detection capability in comparison with a classically processed data (figure 3a) is more remarkable than the previous case because of, probably, more homogeneous nature of the investigated medium.

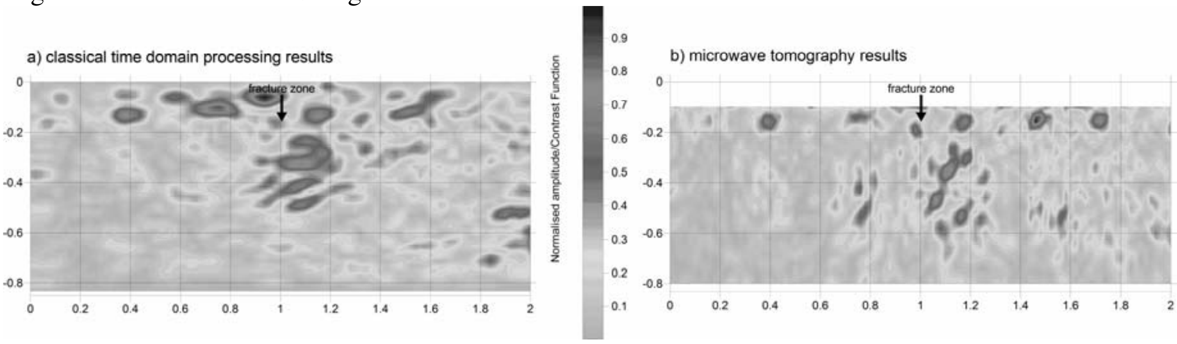


Figure 3. Radargram n. 10 corresponding to the survey line of fig. 1c carried out in the Prefecture of Chania building. a) full classical time domain processing; b) microwave tomography results.

4 CONCLUSION

A GPR survey has been performed at two important historical buildings of the Chania City (Crete, Greece) such as the Venizelos's House and Prefecture of Chania with the aim of investigate the fracture affecting floors and walls. Main problem concerning the GPR fracture detection is the request of high spatial resolution. High frequencies can provide it, but a fundamental role to exploit all available resolution is played by processing. Classical time domain processing approach can help in the focus the images, but it require complex processing session with a constant operator 's intervention. Then, the possibility to apply a novel frequency domain processing routine based on the Microwave tomography under BA assumption has been evaluated.

Firstly, microwave tomography has been used as a substitute of the one-dimensional model based migration, providing well detailed images and a better focusing capability in the fracture zone. Then, the novel processing procedure has been carried out on a merely pre-processed not filtered data providing a results as good as the previous one.

Microwave tomography provided well detailed images which allowed to infer the fracture geometry and their extension in the host medium.

This suggests microwave tomography can be a reliable complete processing tool requiring only the definition of the reference scenario, i.e., the dielectric permittivity and the conductivity of the host medium (soil, floor, wall).

5 REFERENCES

Grandjean, C., Gourry, J.C. 1996. GPR data processing for 3D fracture mapping in a marble quarry (Thassos, Greece). *Journal of Applied Geophysics*, 36: 19-30.

Soldovieri, F., Persico, R., Leone, G. 2006. A Microwave Tomographic Imaging Approach for Multibistatic Configuration: The Choice of the Frequency Step", *IEEE Transactions on Instrumentation and Measurement*, 55(66): 1926-1934.

Soldovieri, F., Hugenschmidt, J., Persico, R., Leone, G. 2007. A linear inverse scattering algorithm for realistic GPR applications. *Near Surface Geophysics*, 5(1): 29-42.

Tsoflias, G.P., Van Gestelz, J.P., Blankenship, D.D., Sen M. 2004. Vertical fracture detection by exploiting the polarization properties of ground-penetrating radar signals. *Geophysics*, 69: 803-810.

6 ACKNOWLEDGMENTS

This work was financed by the international project "Advanced techniques for Seismic RISK Reduction in Mediterranean Archipelago Regions" (SE RISK). The authors are grateful to dr. Pantellis Soupios (TEI-Crete) for the support provided to the project.

3d High resolution ground penetrating radar (GPR): an application for evaluating the state of maintenance of the hypogeum structure in an urban area

G. Leucci, S. Negri
Dipartimento di Scienza dei Materiali, Università del Salento, Italy; e-mail: gianni.leucci@unile.it

Keywords: 3D GPR, velocity analysis, volumetric water content

ABSTRACT.

Ground-penetrating Radar (GPR) is a non-destructive methodology that have become a very important tool for non-destructive underground exploration. For the localisation of buried structures, it uses short time duration electromagnetic (EM) pulses lasting from about 1 ns to about 30 ns. Therefore, GPR is characterised by a wide frequency band ranging from 10 MHz to some GHz, and is useful in the localisation of EM discontinuities in the subsurface with high resolution. This case study shows a practical example of the usage of the 3D GPR technique to evaluate the state of maintenance of an hypogeum structure located in an urban area. The hypogeum structure is in danger of falling because of the numerous fractures present in the rock that constitutes the roof of the same structure. The study was made to assist the design of the restoration works of the hypogeum. Because of the very narrow thickness of the fractures, special care was needed in the acquisition and processing steps. Although pushed to the limit of the resolution achievable by the available antenna, the study has given quite good results.

1 INTRODUCTION

3D GPR has emerged as a significant improvement in technology to acquire more efficiently data and provide high resolution for interpretation (Conyers & Goodman, 1997, Leucci, 2002, Nuzzo *et al.*, 2002). The range of applications, for which 3D GPR data is used, is becoming wide and spans across many domains from utility mapping (Leucci *et al.*, 2002) to evaluating the state of maintenance of building coating (Leucci *et al.*, 2003) and evaluation of karstic cave stability (Leucci, 2003; Leucci & De Giorgi, 2004). This paper presents a reel case study of a 3D GPR acquisition in urban environment in order to mapping the medieval hypogeum structure and to study the state of maintenance.

GPR profiling is applied to identify the hypogeum structure. Subsequently, GPR-based radarfacies pattern are used to determine 3D geometry of hypogeum structure. As a last step the electromagnetic (em) wave velocity was analysed and the dielectric permittivity of rock was esteemed. Using the Topp relationship (Topp *et al.*, 1980) the volumetric water content was esteemed. Volumetric water content can be used to monitoring the high fracture zones inside the rock that constitute the roof of the hypogeum structure.

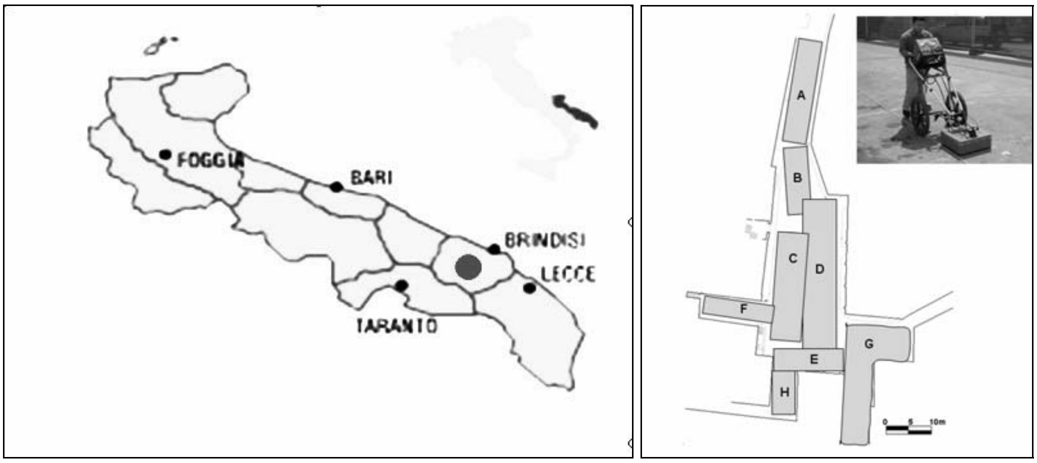
2 THE GPR SURVEY

The hypogeum structure is located in the historical centre of Torre Santa Susanna a village few kilometres south west of Brindisi (figure 1).

The hypogeum structure was dug in the rock in the medieval period. The structure was used to the transformation of the oil using ancient millstones in stone pushed from mules.

They have a great historical value. When it comes to a 3D GPR acquisition, efficiency and precise positioning are essential: efficiency because of the large amount of the data to collect and precise positioning to reconstruct accurately the structure location. For the efficiency aspect we used a Sir 3000 radar system, GSSI cart, collecting roughly 10cm apart. Concerning the positioning aspect in this study a self-tracking laser theodolite was used.

The last aspect that was considered with regard to the radar equipment was the antenna frequency. Since the objective for the customer was to image the first 5m, antenna with 270MHz central frequency was used as a they present a good compromise between resolution and depth penetration. The surveyed area was divided in 8 zones named A, B, C,…..,H respectively (figure 2). In each zone GPR data were acquired in a continuous manner with parallel profiles spaced 0.5m.



Figures 1/2. (left) Location of Torre Santa Susanna; (right) Surveyed area

3. GPR DATA ANALYSIS

GPR enabled to determine the depth and location of the structure (figure 3). The hypogeum structure (FT) is clear evident at the depth of about 1.0m (if the an average em wave velocity of 0.085m/ns is considerate). The area labelled "O" is a window related with the surface and used for inserting the olives in the structure.

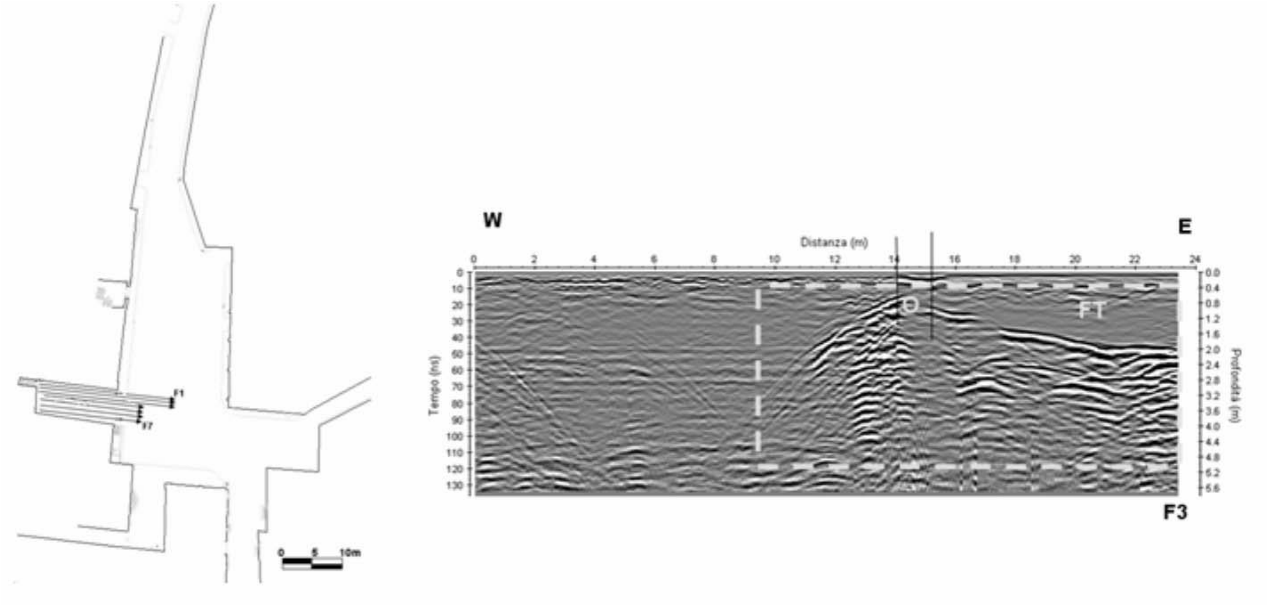


Figure 3. Radar sections acquired in the zone F related to the F3 profile

A way to obtain visually useful maps for understanding the plan distribution of reflection amplitudes within specific time intervals is the creation of horizontal time slices (Conyers & Goodman, 1997). This data representation plays an important role in GPR investigations as it allows an easier correlation of the most important anomalies found in the area at the same depth, thus facilitating the interpretation. In the present work the time slice technique has been used to display the amplitude variations within consecutive time windows of width of 60 ns. The selected two-way time interval corresponds to a soil layer, approximately 2.55 m thick, and the time slices are located between 0.5 and 3.05 m in depth. The slices shown in figure 4 were obtained using the processed data. Several events are visible as high amplitude anomalies that could be interpreted as the ''ipogeo''.

4. EM-WAVE VELOCITY ANALYSIS AND MOISTURE MAP

The em-wave velocity plays an important role in defining shallow subsurface water-content. For the GPR frequency band, the velocity of EM-waves propagating in the ground depends on the relative dielectric permittivity (i.e. the real part of the dielectric constant *K*) of the material (Davis & Annan, 1989). For pure water, *K* is about 80, while for most dry geological material it varies between 4 and 10. If only a small amount of water is contained in the material, the value of *K* will increase considerably and, conversely, the EM-wave velocity will decrease significantly. Thus *K* is a good measure of the water-content in the ground. To determine the water-content the empirical equation, derived by Topp *et al*. (1980), was used.

The em-wave velocity can be estimated from GPR data in several ways (Conyers & Goodman, 1997); it can be more quickly and easily determined from the reflection profiles acquired in continuous mode, using the characteristic hyperbolic shape of reflection from a pointsource (Fruhwirth *et al*., 1996). This is a very common method of velocity estimation and it is based on the phenomenon that a small object reflects EM-waves in almost every direction. In the data set, several hyperbolic reflections caused by stones and objects of small dimensions (figure 3) are present, enabling EM-wave velocity analysis to be performed.

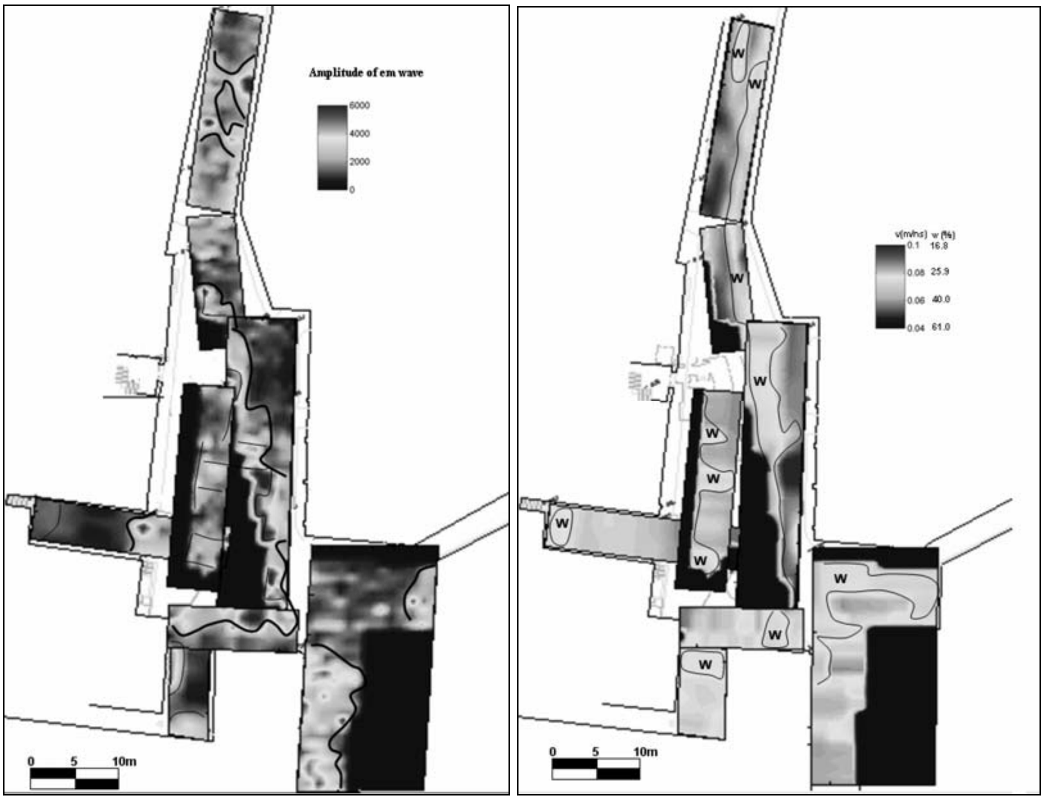


Figure 4. (left) time slice; (right) volumetric water content.

Application of this method gives both vertical (in time, hence in depth) and lateral velocity variations from 0.05 m/ns to 0.12 m/ns. An average velocity of 0.085 m/ns is obtained over the survey area. By applying the empirical Topp formula, we then obtain an estimate of the average volumetric water-content. Figure 4 (right) shows the plan distribution of the volumetric water content. In this figure, the volumetric water-content is also displayed as a time slice using 0–60 ns time window. The w areas, which represents lower velocities, probably corresponds to a higher soil water-content (about 25%). In these areas is high probably that the roof of structure is damage.

5. CONCLUSIONS

GPR technique helped identify the hypogeum structure position in the subsoil. The existence in the radar sections of several hyperbolic anomalies, due to small inhomogeneities, made possible a quick and quite accurate EM-wave velocity analysis. This, in turn, made it possible to highlight, in a quantitative way, the water-content variations underground. It allow to individualize the higher water content zones inside the roof of the structure. Consequently these zones are probably more damage.

6. REFERENCES

Conyers, L.B., Goodman, D. 1997. *Ground-penetratingRadar—an Introduction for Archaeologists*. Alta Mira Press: Walnut Creek.

Davis, J.L., Annan, A.P. 1989. GPR for high resolution mapping of soil and rock stratigraphy. *Geophysical Prospecting* , 37 : 531–551.

Fruhwirth, R.K., Schmoller, R., Oberaigner, E.R. 1996. Some aspects of the estimation of electromagnetic wave velocities. *Proceedings of the 6th International Conference on GroundPenetrating Radar*, Tohoku University, Sendai, Japan, pp. 135–138.

Leucci, G. 2002. Ground-penetrating radar survey to map the location of buried structures under two churches, *Archaeological Prospection*, 9 (4): 217-228.

Nuzzo, L., Leucci, G. , Negri, S., Carrozzo, M.T., Quarta, T. 2002. Application of 3d visualization techniques in the analysis of GPR data for archaeology, *Annals of Geophysics*, 45 (2): 321-337.

Leucci, G., Negri, S., Carrozzo, M.T., Nuzzo, L. 2002. Use of ground penetrating radar to map subsurface moisture variations in an urban area, *Journal of Environmental and Engineering Geophysics*, 7 (2) : 69-77.

Leucci, G., Negri, S., Carrozzo, M.T. 2003. Ground penetrating radar: an application for evaluating the state of maintenance of the building coating, *Annals of Geophysics*, 46 (3) : 481-489.

Leucci, G. 2003. Evaluation of karstic cave stability using integrated geophysical methods, *GeoActa*, 2 : 47-60.

Leucci, G., De Giorgi, L., 2004. Integrated geophysical surveys to assess the structural conditions of a karstic cave of archaeological importance, *Natural Hazards and Earth System Sciences*, 5 : 17-22;

Topp, G.C., Davis, J.L., Annan A.P. 1980. Electromagnetic determination of soil water content: measurements in coaxial transmission lines, *Water Resources Research* 16(3) : 574–582.

Integrated geophysical investigations at the Martyrium of Saint Philip, Hierapolis, Turkey

M. T. Carrozzo[1], G. Leucci[2], S. Negri[2], L.Nuzzo[2,3]

1 Dipartimento di Scienza dei Materiali, Università del Salento, Lecce, 73100, Italia, mteresa.carrozzo@unile.it

2 Università del Salento, Lecce, Italia, gianni.leucci@unile.it; sergio.negri@unile.it; luigina.nuzzo@unile.it

3 Keele University, Keele, U.K., l.nuzzo@esci.keele.ac.uk

Keywords: Geophysics, Archaeology, St. Philip Martyrium, Hierapolis, Turkey

ABSTRACT.

In 2001-2003 extensive geophysical surveys involving several methods have been performed inside the archaeological site of Hierapolis, Denizli, Turkey, by the geophysical group of the University of Lecce in collaboration with the University of Bari, to support the archaeological excavations being carried out by the Italian Archaeological Mission in Hierapolis (Turkey), coordinated by Prof. F. D'Andria. The study area is located about 250 km East of Izmir, near the Pamukkale village, well renown for the white travertine pools, created by calcareous thermal waters flowing down steep faults at the border of the archaeological site. Hierapolis was one of the most important Hellenistic-Roman cities in Asia Minor. Now it is a UNESCO World Heritage site because of its magnificent archaeological remains and its peculiar geo-hydrogeological and geothermal setting.

This work reports the results of the integrated geophysical surveys performed inside the Martyrium of Saint Philip, a mausoleum built on a hill outside the city walls where it is believed that the Apostle has been martyred. The religious complex was connected to the city centre by a devotional staircase path, recently brought to light by the Italian Archaeological Mission thanks to the interpretation of remote-sensing imagery. The Martyrium has a complex square plan with a central octagonal room surrounded by eight large rectangular rooms and a series of smaller debris-filled rooms. Ground penetrating radar (GPR), electrical resistivity tomography (ERT), magnetic gradient and seismic refraction tomography were carried out in the octagonal room, whereas only GPR and ERT were used for surveying the rectangular rooms. The acquisition was performed along a series of closely spaced lines and processed/visualized as 2D sections (GPR, ERT and seismic), map view (magnetic gradiometry) or 3D volumes (GPR and ERT). The results of the integrated geophysical investigations revealed a series of anomalies in both the central and lateral rooms that could be ascribed to the pillars foundations and to other possible archaeological structures, and in particular to tombs.

1 INTRODUCTION

The non-invasive nature of geophysical prospecting and remote sensing methods makes their use an increasingly vital complement to invasive archaeological investigations (Scollar *et al.*, 1990). Among them Ground Penetrating Radar (GPR) plays a special role because of the high resolution achievable through the use of high-frequency antennas (Basile *et al.*, 2000; Nuzzo *et al.*, 2002; Carrozzo *et al.*, 2003).

Extensive geophysical measurements have been carried out in 2001-2003 in the archaeological site of Hierapolis (Denizli, Turkey) as a support for the archeological investigations being carried out by the Italian Archaeological Mission coordinated by Prof. F. D'Andria (D'Andria & Caggia, 2007). The geophysical surveys were performed by the geophysical group of the University of Lecce in collaboration with the University of Bari in the framework of research projects funded by the Italian Space Agency (ASI) and the National Research Council (CNR).

The study area (figure 1a) is located about 250 km East of Izmir, on a plateau on the southern bank of the Menderes River valley. Hierapolis was one of the most important Hellenistic-Roman cities in Phrygia, located along a route linking the internal part of Anatolia to the Mediterranean (D'Andria & Silvestrelli, 2000). Its archaeological ruins are located near a village in the province of Denizli, named in Turkish Pamukkale, i.e. "castle of cotton", after the magnificent white travertine pool formations, created by calcareous thermal waters flowing down the steep fault escarpment that borders the archaeological site. For its peculiar archaeological as well as geological, hydrogeological and geothermal setting, Hierapolis is now a UNESCO World Heritage site. Because of the site complexity, the geophysical campaigns had manifold aims: highlight interesting zones and potential targets for subsequent excavations, gain information non-invasively on the subsurface below archaeological structures or in areas impossible to excavate, and complement Remote Sensing and geological surveys to provide a general overview of the geological-archaeological setting of the site (Carrozzo *et al.*, 2002; Negri *et al.*, 2003; Negri & Leucci, 2006).

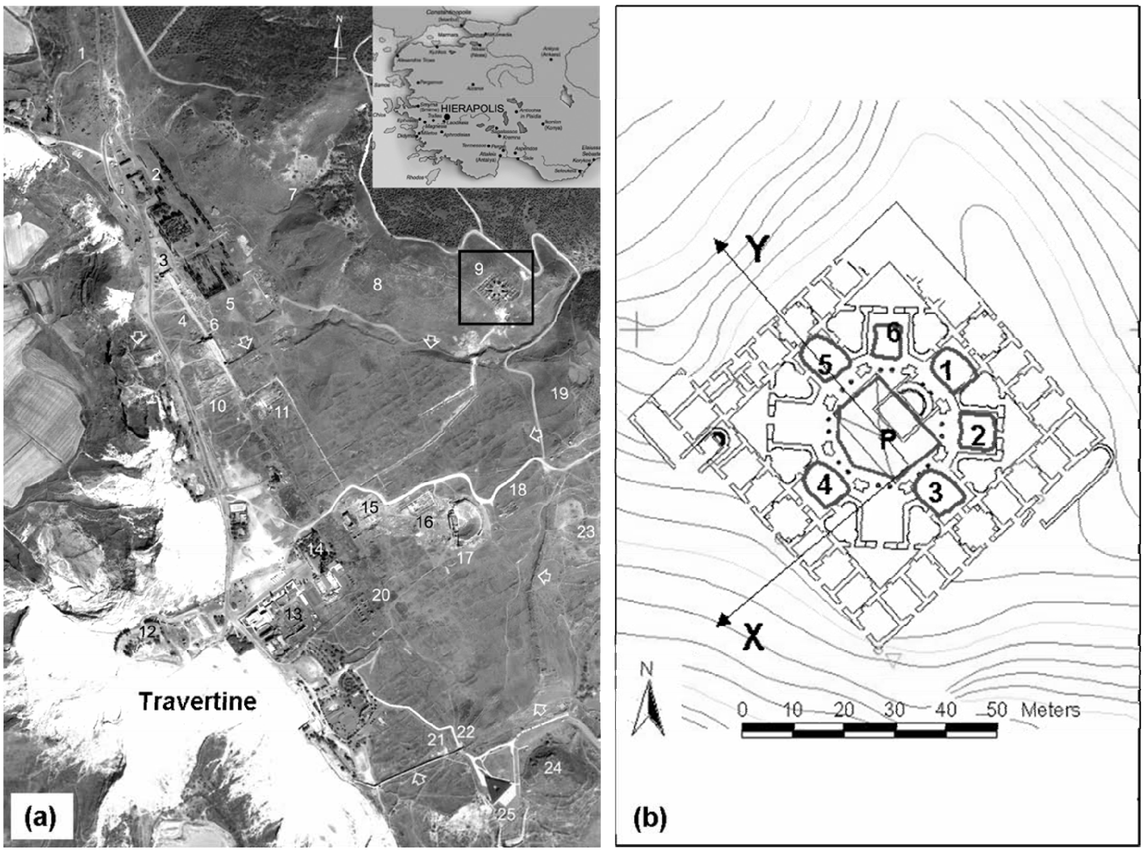


Figure 1. (a) Location map (inset) and satellite panchromatic image (2005) showing the necropolis (1) and the urban area (2-25) of Hierapolis. The numbers denote the zones excavated by the Italian Archaeological Mission in 1957-2007, including the Martyrium of Saint Philip (9) investigated with geophysical methods. (Reproduced from Ufficio Stampa CNR, 2008). (b) Location map of the 2003 geophysical surveys inside the Martyrium of Saint Philip: GPR, ERT, magnetic gradient and seismic refraction (octagonal area P); GPR and ERT (room 1); only GPR (2-6).

This work reports the results of the integrated geophysical surveys performed in 2003 inside the Martyrium of Saint Philip, a mausoleum built on a hill outside the city walls (9 in Figure 1a) in the place where it is believed that the Apostle has been martyred. The religious complex dates back to the 4th-5th century AD, when Hierapolis became a reference point for the Christianity in Asia Minor. It was connected to the city centre by a devotional staircase path, recently brought to light by the Italian Archaeological Mission thanks to the interpretation of remote-sensing imagery (Ufficio Stampa CNR, 2008). The intent to reconstruct the Martyrium and the annexed buildings discovered along the excavated path, in order to restore this processional route for modern visitors, adds a renowned interest toward the results of the geophysical surveys in this area.

2 GEOPHYSICAL INVESTIGATIONS INSIDE THE MARTYRIUM

The Martyrium has a complex square plan with a central octagonal room originally covered by a dome. Eight rectangular rooms radiate from the central room and are surrounded by a series of smaller debris-filled rooms. Ground penetrating radar (GPR), electrical resistivity tomography (ERT), magnetic gradient and seismic refraction tomography were carried out in the octagonal room, whereas only GPR and occasionally ERT were used for surveying the accessible rectangular rooms (Figure 1b).

The acquisition was performed using the following instrumentation and survey setting:

- GPR: Sir System 2 (GSSI) equipped with 200 MHz and 500 MHz antennas; 0.5 m spaced survey lines with ~ 2 cm average inline spacing;
- ERT: 48-channel geo-resistivimeter Syscal R1 (Iris Instruments); dipole-dipole 1 m spaced parallel lines with 1 m electrode distance;
- magnetometry: GSM-19 Overhauser gradiometer (GEM System Inc), with sensors at 0.5 m and 1.5 m height above ground; 1 m by 1 m readings.

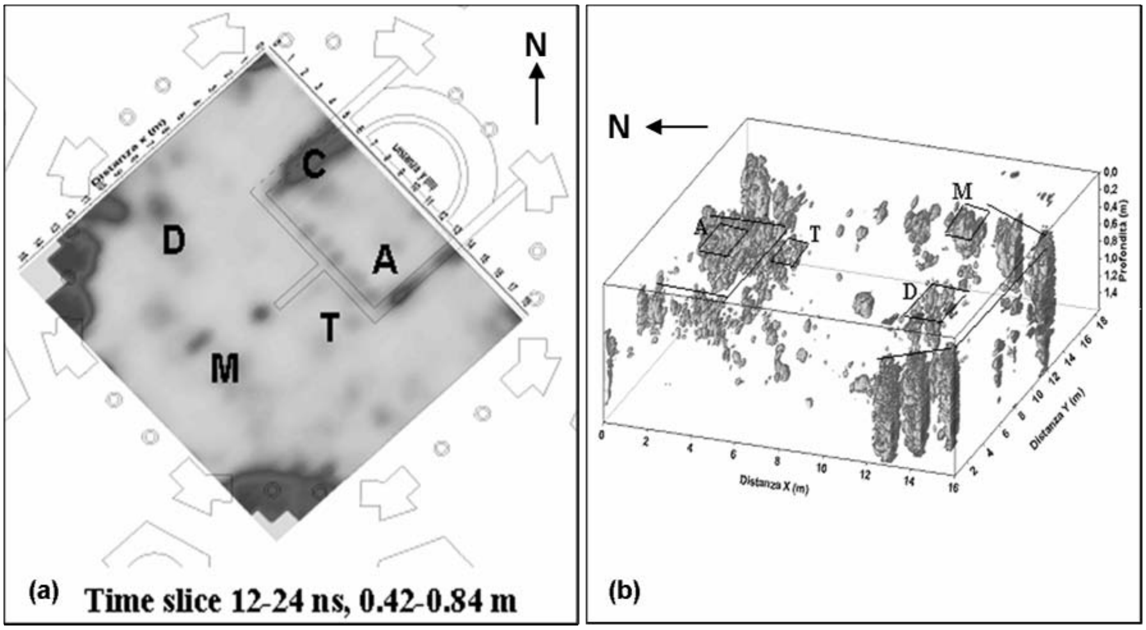


Figure 2. Main results of the GPR survey inside the octagonal room P visualized as (a) time-slice map or (b) 3D volume showing only the most reflective anomalies (red-purple).

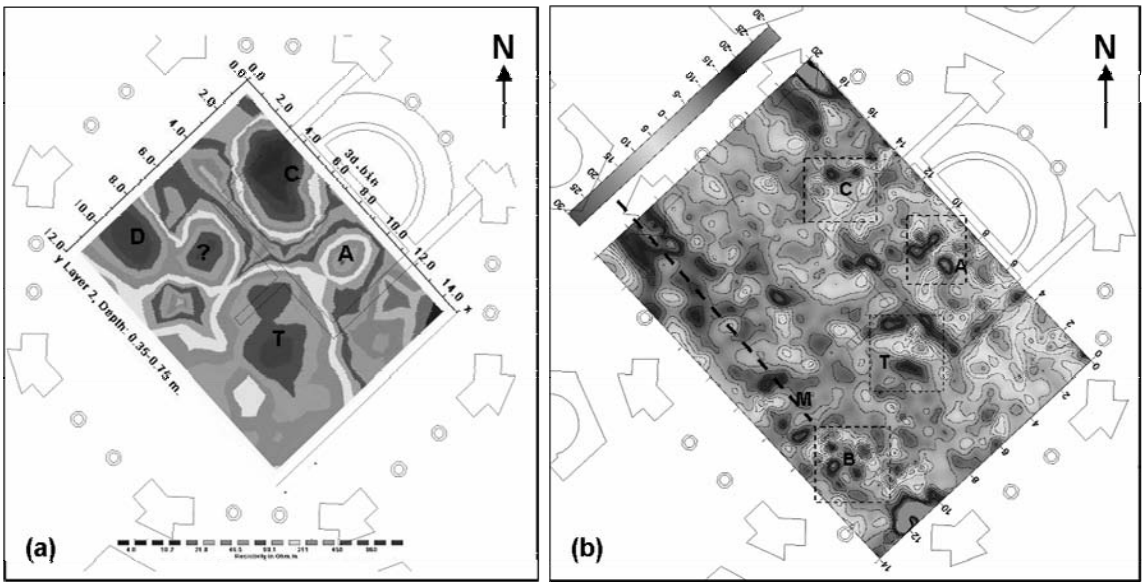


Figure 3. Main results of (a) ERT and (b) magnetic gradient surveys inside the octagonal room P.

The data were processed and displayed using appropriate software packages to outline underground anomalies of possible anthropogenic origin. After standard 2D processing (static corrections and trace regularization, 1D and 2D filtering, gain, velocity analysis and migration) GPR data were combined into 3D volumes and visualized as vertical sections, time-slice maps or iso-surface volumes to allow a robust interpretation and spatial correlation of the electromagnetic anomalies. The apparent resistivity sections were inverted individually to obtain 2D resistivity tomography sections or merged and inverted all together to obtain a 3D tomographic cube, which was subsequently visualized as vertical cross-sections or horizontal depth-slices. The magnetic data were processed and displayed as a magnetic gradient map.

The main results from the survey inside the octagonal area P are shown in figures 2 and 3. Very high-amplitude GPR anomalies are visible close to existing structures, namely under the marble paving between the columns and pillars bordering the octagon and below the rectangular remnants of the altar (red-purple in figure 2), and are interpreted as building foundations. Other less intense anomalies have no correlation with superficial features and could be due to possible archaeological structures (voids, tombs) or embedded heterogeneities (travertine blocks, boulders). Most of the radar anomalies correlate well with high-resistivity zones (figure 3a) and localized magnetic anomalies (figure 3b). Two anomalies (? in Figure 3a and B in figure 3b) have no evidence in the GPR results.

3 CONCLUSIONS

The results of the integrated geophysical investigations inside the Martyrium of Saint Philip revealed a series of anomalies in both the central and lateral rooms that could be ascribed to the building foundations and to other possible archaeological structures, and in particular to tombs.

4 REFERENCES

Basile, V., Carrozzo, M. T., Negri, S., Nuzzo, L., Quarta, T., Villani, A. V. 2000. A ground-penetrating radar survey for archaeological investigations in an urban area (Lecce, Italy), *Journal of Applied Geophysics*, 44: 15-32.

Carrozzo, M. T., Leucci, G., Margiotta, S., Negri, S., Nuzzo, L., Ricchetti, E. 2002. Indagini geofisiche nel sito archeologico di Hierapolis (Turchia) ed integrazione con immagini da satellite ad alta risoluzione, in *Riassunti estesi delle Comunicazioni 21° Convegno Nazionale del GNGTS*, Roma, 19-21 Novembre 2002, 339-340.

Carrozzo, M. T., Leucci, G., Negri, S., Nuzzo, L. 2003. GPR Survey to understand the stratigraphy of the Roman Ships Archaeological Site (Pisa, Italy), *Archaeological Prospection*, 10: 57-72.

D'Andria, F., Caggia, M. P. 2007. *Hierapolis di Frigia I. Le attività delle campagne di scavo e restauro 2000-2003*. Istanbul.

D'Andria, F., Silvestrelli, F. 2000. *Ricerche archeologiche turche nella valle del Lykos*. Congedo Editore, Galatina.

Negri, S., Leucci, G., Nuzzo, L. 2003. Indagini geofisiche nel Martirium di San Filippo nel sito archeologico di Hierapolis (Turchia), in *Riassunti estesi delle Comunicazioni 22° Convegno Nazionale del GNGTS*, Roma, 18-20 Novembre 2003, 386.

Negri, S., Leucci, G. 2006. Geophysical investigation of the Temple of Apollo (Hierapolis, Turkey), *Journal of Archaeological Science,* 33: 1505-1513.

Nuzzo, L., Leucci, G., Negri, S., Carrozzo, M. T., Quarta, T. 2002. Application of 3D visualization techniques in the analysis of GPR data for archaeology, *Annals of Geophysics*, 45: 321-337.

Scollar, I., Tabbagh, A., Hesse, A., Herzog, I. 1990. *Archaeological prospecting and remote sensing*. Cambridge.

Ufficio Stampa CNR, 2008. Sulle orme di San Filippo, Comunicato Stampa 6/2008 www.stampa.cnr.it/docUfficioStampa/comunicati/italiano/2008/Gennaio/6_gen_2008.doc

Magnetic and Electrical integrated approach for the investigation of an archaeological site at Kassaneva-Devinu (Greece)

D. Chianese[1], B. Di Fiore[2]

1 Institute of Methodologies for Environmental Analysis, C.da S. Loja Tito Scalo. Italy. E-mail: chianese@imaa.cnr.it
2 Institute for Space Applications and Remote Sensing (ISARS) – National Observatory of Athens – Athens, Greece.
E-mail: boris@space.noa.gr

Keywords: Archaeology; Resistivity; Magnetometry; Kassaneva-Devinu

ABSTRACT.

In this work we present the main results of the integrated application of magnetic and geoelectrical techniques applied to the study of a Neolithic archaeological site of Kassaneva-Devinu (Greece), with the aim to obtain indication about the presence of buried structures of antrohopic origin. This high resolution geophysical campaign was carried out in the framework of a collaboration project between the Department for the Cultural Heritage of the University of Salerno and the Institute of Methodologies for the Environmental Analysis of the National Research Council of Tito Scalo.

The survey was organised in two steps: first we carried out a high resolution magnetic survey (31 profiles, 1m spaced) covering a broad area (about 900 squares meters) pointed by the archaeologists on the basis of previous campaign surveys; successively, on the basis of the evidences resulting from the magnetic map, we carried out a high resolution geoelectrical survey, consisting of 21 profiles, 1.5m spaced, covering a broader area (about 1060 squares meters). Finally, comparing the results coming from the two geophysical investigations, we obtained information about the under surface displacement of buried remains. In such a way, it was possible to establish what were the most probable points where making excavation tests. In fact, on the basis of the indications coming from the geophysical survey, the archaeologists carried out 8 excavation tests, bringing to light the remains of the walls of an ancient settlement. These results confirm the fact that the use of integrated geophysical methods for archaeological purposes allows the archaeologists to reduce both the time and the costs of their invasive interventions.

1 INTRODUCTION

During the last years, the application of non-invasive electromagnetic techniques for archaeological investigation became an almost usual tool to help the archaeologists to limit the areas to be excavated, in such a way to reduce the time and cost of archaeological campaigns. In this framework, the most suitable geophysical investigation techniques employed for archaeological purposes are the magnetic method (Bates & Bates, 2000; Bavusi *et al.*, 2004; Chavez *et al.*, 1995; Chavez *et al.*, 2001; Godio & Piro, 2005; Powell *et al.*, 2002) and the geoelectrical method (Cammarano *et al.*, 2000; Di Fiore & Chianese, 2008; Sambuelli *et al.*, 1999; Tsokas *et al.*, 1994). In fact, they provide non-destructive and broad range of application means of exploring for the archaeological purpose, especially because they are non-invasive and prompt techniques.

In this paper we show the main results derived by the application of high resolution 2D electrical resistivity tomographies and magnetic method, aimed to the identification of buried structures at the Neolithic archaeological site of Kassaneva-Devinu (Greece) (figure 1).

The geophysical results, obtained combining advanced technologies for data acquisition and new methods for data elaboration and inversion (Ciminale & Loddo, 2001; Loke & Barker, 1996), allowed us to reconstruct part of the buried structures of the ancient settlement.

In fact, on the basis of the information provided by the geophysical survey, the archaeologists carried out eight excavation tests, which brought in light part of the remains of buried walls.

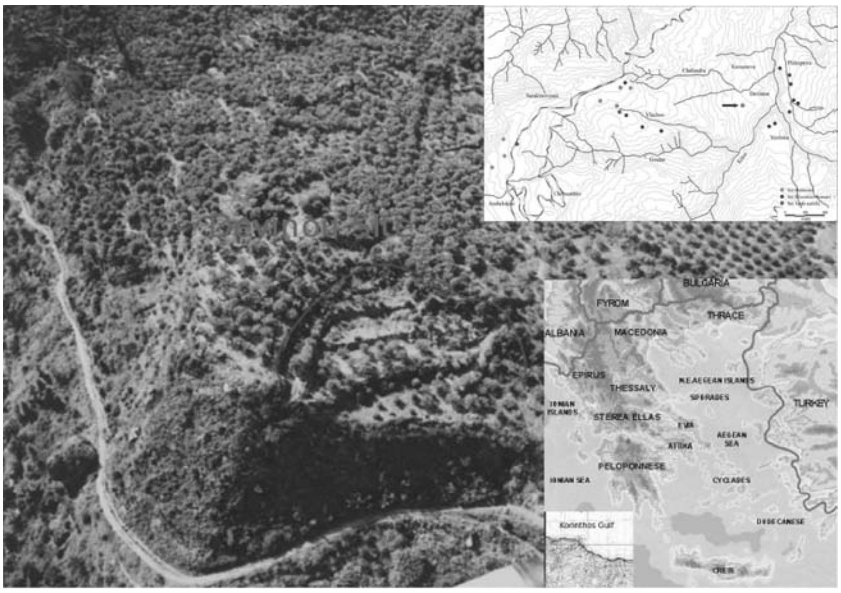


Figure 1 – Location of the investigated site. In the upper right map are indicated the most important archaeological sites in the neighbourhood of Devinou site (black arrow): Prehistoric sites (green); Hellenistic - Roman sites (blue); Late Ancient sites (red).

2 GEOPHYSICAL METHODS

The geophysical survey involved the integrated application of both magnetic and electric techniques, applied in a broad area identified by the archaeologists of the Department for the Cultural Heritage of the University of Salerno on the basis of previous reconnaissance and excavation tests.

2.1 Magnetic Measurements

The magnetic survey was carried out by means of the use of an optical pumping magnetometer G-858 Geometrics in gradiometric configuration with the two magnetic sensors put at a vertical distance of about 0.8m between; such a configuration allows us to acquire two simultaneous magnetic signals, deriving from two different quotes and then their vertical gradient. In such a way, it is possible to remove the diurnal variations of the heart magnetic field, so that by analysing the gradiometric map, we can detect the anomalous values due to the presence of buried structures or objects provided with remaining magnetization. The sample rate was set at 10Hz, with the possibility to obtain a great deal of experimental data in a relatively brief time range, in order to provide as higher resolution as possible magnetic maps.

In the investigated area we performed a $30mx30m$ magnetic map, whose limits were set on the basis of the information derived from the archaeologists indications. The magnetic measurements were organised in 31 parallel profiles put at a distance of 1m between in the x direction, with a sample rate of 0.5m in the y direction, comparable with the dimension of buried structures put in light during the previous excavation tests (fig. 2).

2.2 Electric Resistivity Tomography (ERT)

The ERT technique allows to obtain high-resolution images of the resistivity subsurface patterns and it is largely applied in the study of a wide class of geological and environmental problems (i.e. structural studies, fault mapping, landslide surveying, polluted site monitoring, etc..) (Caputo *et al.*, 2003; Colella *et al.*, 2004; Lapenna *et al.*, 2005). The geoelectrical method is nowadays applied also for archaeological purposes, because of the buried targets (walls, roof, road, etc.) present different electrical peculiarities (electrical resistivity) in respect of the homogeneous surrounding soil (Rizzo et al. 2005).

The electric survey was carried out in an area of 35.25mx30m, containing the whole area object of the previous magnetic investigation. In fact, this area was selected after the preliminary analysis of the magnetic data. The electric measurements were performed with 21 parallel profiles put at a distance of 1.5m between in the y direction, covering an area of about 1060sqm. The distance between the 48 electrodes was 0.75m. In such a way, we could obtain a reconstruction of the investigated soil by means of the analysis of slices parallel to the ground surface and with a resolution comparable with the dimension of the buried structures.

3 RESULTS

3.1 Magnetic Results

In figure 2 we show the resulting gradiometric map, covering an area of about 900sqm. This gradiometric map results from a pre-elaboration process, involving the employment of an automatic filtering procedure, based on robust statistical basis, which allows to identify, remove and substitute the magnetic anomalous spikes often present in the magnetic data, due to the presence of shallow metallic object, in this case iron sticks left after the archaeological survey. The theoretical aspects of this procedure are presented in a previous paper (Chianese et al., 2004).

As you can easily observe, there are two areas, evidenced by red boxes, a reference to a rectangular shape, which could suggest the presence of buried settings. The first area, smaller, is located at a distance between 18m and 24m in the x direction; while the second area, extends in the x direction at a distance between 13m and 23m. Finally, an longed anomaly, with the same magnetic intensity of the previous, can be observed at the centre of the map, at about 14m in the y direction, in a range coming from 5m to 17m in the x direction.

These evidenced have been confirmed by the results coming from the ERT investigation, which confirmed the presence of buried structures in correspondence of the magnetic anomalies, with shape and dimension comparable with those derived by the magnetic investigation.

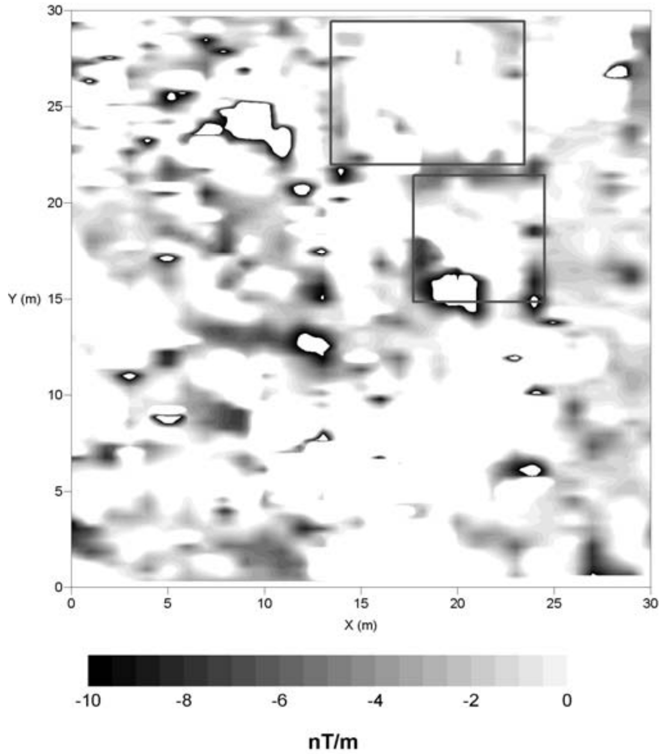


Figure 2 – Gradiometric map. The red boxes evidence the most interesting results.

3.2 Electrical Resistivity Results

The apparent resistivity data were interpreted by means of the use of the RES2DINV software (Loke & Barker, 1996), which allows to automatically set a 2D resistivity model, starting from the surface experimental data.

The electrical results are represented as slices parallel to the ground surface, and set at different depths in the subsoil, automatically distributed by the inversion software. In our case, we put in evidence the slice located at a depth of 0.5m, which seems to show the most interesting results (fig. 3). This slice shows a number of *basin* or *pit* anomalies, apparently filled with more conductive clayey material (lower values of electrical resistivity).

These anomalies could be due both to the presence of tree pits or to the foundation of archaeological structures. Starting from these evidences, after the geophysical survey an excavation test was carried out

(2x1sqm), in correspondence of the line 22.5m, at a distance ranging from 25m and 29m, an area including both the anomalies coming from the magnetic and the electric investigations. The excavation brought in light at a depth of 0.6m and in correspondence of the indicated area the trace of a blocks wall, having in plant a thickness of about 0.45m (fig. 4). For completeness, we observe that the more resistivity values in the western part of the map were due to the surrounding bedrock, partially outcropping on the surface.

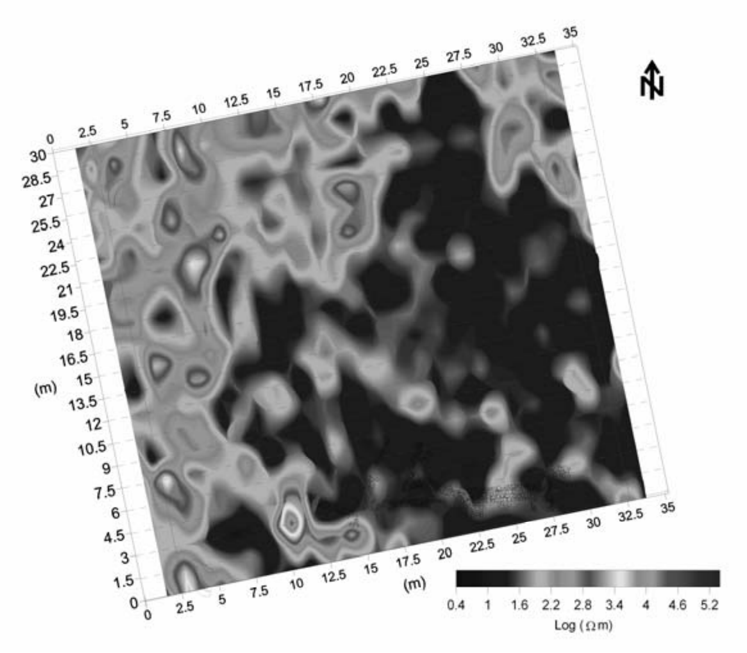


Figure 3 – Slice of calculated electric resistivity at a depth of 0.5m

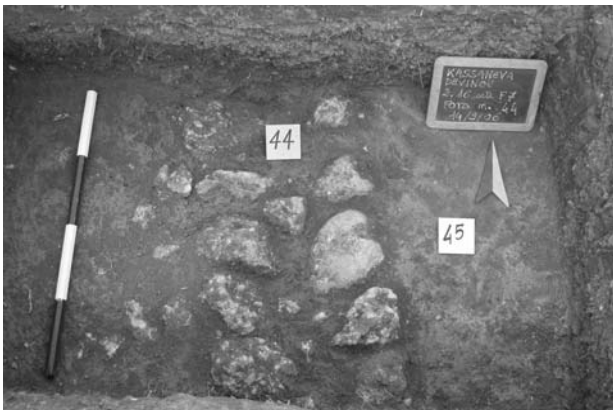


Figure 4 – Trace of a wall put in light by an excavation test in correspondence of geophysical anomalies

4 REFERENCES

Bates, M.R., Bates, C.R. 2000. Multidisciplinary approaches to the geoarchaeological evaluation of deeply stratified sedimentary sequences: examples from Pleistocene and Holocene deposits in Southern England, United Kingdom. *Journal of Archaeological Science* 27: 845–858.

Bavusi, M., Chianese, D., Giano, S.I., Mucciarelli, M. 2004. Multidisciplinary investigations on the Roman aqueduct of Grumentum (Basilicata-Southern Italy). *Annals of Geophysics* 47/6: 1791-1802.

Cammarano, F., Di Fiore, B., Mauriello, P., Patella, D. 2000. Examples of application of electrical tomographies and radar profiling to cultural heritage. *Annals of Geophysics* 43/2: 309-324.

Caputo, R., Piscitelli, S., Oliveto, A., Rizzo, E., Lapenna, V. 2003. High-resolution resistivity tomographies in Active Tectonic studies.Examples from the Tyrnavos Basin, Greece. *Journal of Geodynamics* 36: 19-35.

Chavez, R.E., Hernandez, M.C., Herrera, J., Camara, M.E. 1995. A magnetic survey over La Maya, an archaeological site in Northern Spain. *Archaeometry* 37: 171-184.

Chavez, R.E., Camara, M.E., Tejero, A., Barba, L., Manzanilla, L. 2001. Site characterization by geophysical methods in the archaeological zone of Teotihuacan, Mexico. *Journal of Archaeological Science* 28: 1265–1276.

Chianese, D., D'Emilio, M.G., Di Salvia, S., Lapenna, V., Ragosta, M., Rizzo, E. 2004. Magnetic mapping, Ground Penetrating Radar surveys and magnetic susceptibility measurements for the study of the archaeological site of Serra di Vaglio (Southern Italy). *Journal of Archaeological Science* 31/5: 633-643.

Ciminale, M., Loddo, M. 2001. Aspects of Magnetic Data Processing. *Archaeological Prospection* 8: 239-246.

Colella, A., Lapenna, V., Rizzo, E. 2004. High-resolution imaging of the High Agri Valley basin (Southern Italy) with Electrical Resistivity Tomography. *Tectonophysics* 386: 29-40.

Di Fiore, B., Chianese, D. 2008. Electric and magnetic tomographic approach for the geophysical investigation of an unexplored area in the archaeological site of Pompeii (Southern Italy). *Journal of Archaeological Science* 35/1: 14-25.

Godio, A., Piro, S. 2005. Integrated data processing for archaeological magnetic surveys. *The Leading Edge* 24: 1138–44.

Lapenna, V., Lorenzo, P., Perrone, A., Piscitelli, S., Rizzo, E., Sdao, F. 2005. 2D electrical resistivity imaging of some complex landslides in Lucanian Apennine (Southern Italy). *Geophysics* 70: 11-18.

Loke, M.H., Barker, R.D. 1996. Rapid least-squares deconvolution of apparent resistivity pseudosections using a quasi-Newton method. *Geophysical Prospecting* 44: 131-152.

Powell, A.J., McDonnell, J.G., Batt, C.M., Vernon, R.W. 2002. An assessment of the magnetic response of an iron-smelting site. *Archaeometry* 44/4: 651–665.

Rizzo, E., Chianese, D., Lapenna, V. 2005. Magnetic, GPR and geoelectrical measurements for studying the archaeological site of 'Masseria Nigro' (Viggiano, Southern Italy). *Near Surface Geophysics* 3/1: 13-19.

Sambuelli, L., Socco, L.V., Brecciaroli, L. 1999. Acquisition and Processing of Electric, Magnetic and GPR Data on a Roman Site (Victimulae, Salussola, Biella). *Journal of Applied Geophysics* 41: 189-204.

Tsokas, G.N., Giannopoulos, A., Tsourlos, P., Vargemezis, G., Tealby, J.M., Sarris, A., Papazachos, C.B., Savvopoulou, T. 1994. A large scale geophysical survey in the archaeological site of Europos (N. Greece). *Journal of Applied Geophysics* 32: 85-98.

Application of Integrated Geophysical Prospection Techniques for Mapping Ancient Sikyon, Greece

B. Gourley[1], Y. Lolos[2], A. Sarris[3]

1 Department of Archaeology, University of York, Kings Manor, York, YO17EP, United Kingdom, rbg4@york.ac.uk
2 Department of History, Archaeology and Social Anthropology, University of Thessaly Argonafton and Filellinon, Volos, Greece 38221, lolos@hol.gr
3 Laboratory of Geophysical - Satellite Remote Sensing & Archaeo-environment, Foundation for Research & Technology, Hellas (F.O.R.T.H.), Institute for Mediterranean Studies (I.M.S.), Melissinou & Nik. Foka 130, PO. Box 119, Rethymnon 74100, Crete, Greece, asaris@ret.forthnet.gr

Keywords: Sikyon, Geophysical, magnetic, resistance, GPR, ERT, GIS.

ABSTRACT:

Sikyon, an important city in Northern Peloponnese, was refounded in 303 BC on a plateau rising some 4 km south-west of the Corinthian gulf and covering an approximate surface of 250 hectares. Our previous knowledge of the archaeology of this city was limited to a few excavated public monuments in and near the ancient agora. The Sikyon survey project was launched in 2004 under the direction of Yannis Lolos in collaboration with the 37th Ephorate of Prehistoric and Classical Antiquities, the Institute of Mediterranean Studies and the University of York. It purports to explore the archaeology of the vast urban area of ancient Sikyon through intensive surface survey, geophysical prospection, geo-archaeological survey and study of rescue excavations.

The goal of the geophysical survey is to explore the layout of the city and its architectural remains, and to investigate the relation of the surface data collected by the intensive survey to the sub-surface archaeology. To this aim geophysical research has included areas of high as well as low surface artefact distribution, and focused at the center of the city as well as at its periphery. So far some 86 hectares have been covered through surface survey and approximately 33 hectares with geophysical methods, mainly magnetic and soil resistance techniques. Our prolific results have been of astonishing breadth and clarity, favored by the soil conditions, the geology of the plateau and the history of the area. The size and shape of the agora of the ancient city have been now almost definitely established, and the interface between the agora and the city-quarters sufficiently explored. A number of monuments have been traced inside and outside the agora including temples, porticoes, a basilica, street lines, houses and industrial installations. The dozens of streets and intersections that we have detected around the plateau have helped us to reconstruct the grid of the Hellenistic and Roman city, and to investigate uses of space in different quarters of the city.

In addition, survey of selected areas with the Ground Penetrating Radar (GPR) and electrical resistance tomography (ERT) has produced a set of stratigraphic readings to which we can assign chronological phases based on comparison with data from rescue and past excavations. Certain areas of the plateau have been covered with more than one geophysical methods, and this has allowed us to check the accuracy and detail of different techniques and to measure their applicability to the conditions prevailing in the plateau.

All of the above information have been fused into a GIS platform for a better management and interpretation of the diverse datasets. Ultimately our geophysical results will help us to understand the archaeology of this large urban area and will serve as a guide for proper management of its rich cultural heritage.

1 INTRODUCTION

In 2004 the Sikyon Survey Project began with the aim of the exploration of the archaeology and paleoenvironment of the site of the Hellenistic City of Sikyon in southern Greece. This interdisciplinary study incorporates geophysical survey in parallel with intensive fieldwalking survey at the heart of the archaeological investigation. In this context, geophysical survey provides valuable information concerning the character and preservation of subsurface deposits across the study area, and with other forms of remote sensing, it significantly contributes to the analysis of surface/ subsurface relationships at such a site (Lolos *et al* 2007). At 237 hectares the survey area poses significant challenges of scale for both fieldwalking and geophysical survey and this paper presents the combined approaches that have been introduced to maximize the potential for the two survey methods to be successfully integrated.

From the 7th century BC it is known that Sikyon was a place of importance, benefiting from its coastal location approximately 16km west of Corinth. The total surface area of the plateau (excluding the fenced area of the ancient civic centre (agora) is approximately 240 hectares of which approximately 57 is covered by the modern village of Vasiliko. The remaining 180 hectares is subdivided into irregular fields of modest size. Ancient literary sources record that the plateau acted as the acropolis of the Archaic and Classical city which was located 4km north on the coast. Sikyon flourished from the Archaic period onwards, but in 303 BC it was destroyed by Demetrios Poliorcetes, who refounded and relocated the city on the plateau. The city prospered in the Hellenistic and Roman periods but by the late Roman period we know little and it is not until the13th and 14th centuries, that Sikyon reappears this time under the name of Vasilika or Vasiliko.

2 SURVEY DESIGN AND PRACTICAL IMPLEMENTATION.

The Sikyon survey project employs a recording system that is based on the designation of three survey zones which roughly correspond to dominant trends in local topography (Lolos *et al.,* 2007). These include the Upper Plateau which stands approximately 50m above and to the west of the main body of the survey area; the North Plateau, covering the gently sloping agricultural land to the northeast of the site; and finally the South Plateau, which comprises a more varied topography and range of crops. Excluded from these zones are the area of the modern village in the southeast of the site, and the former civic core of the ancient site (the agora) which is located at the heart of the plateau and under protection as a scheduled archaeological site.

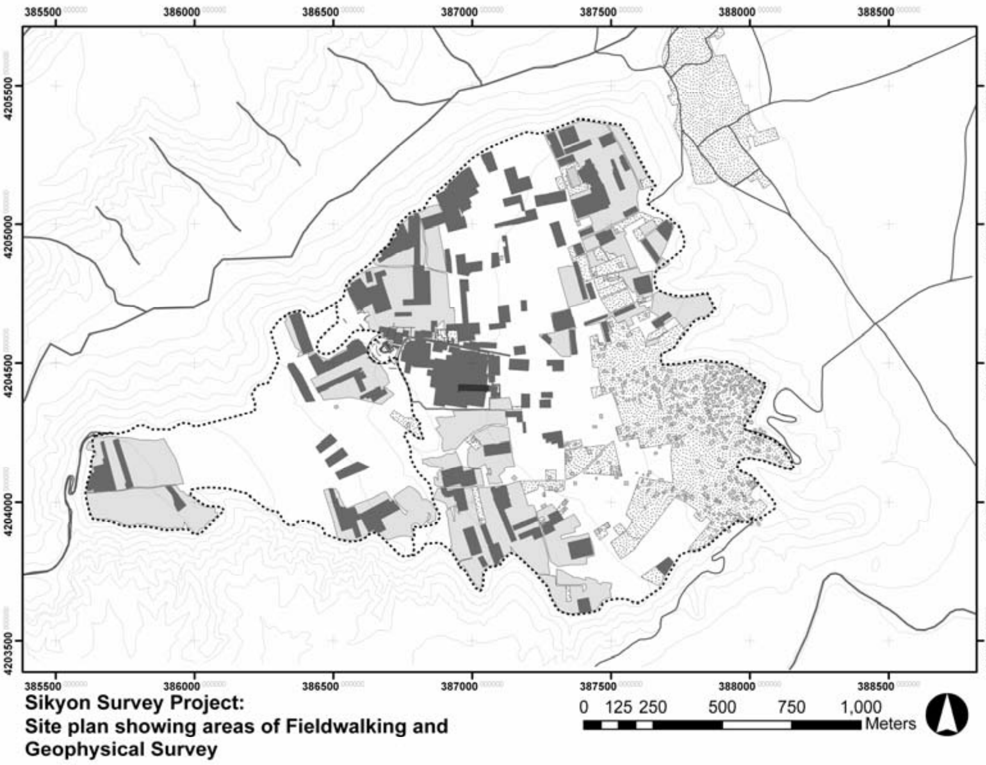


Figure 1: Site plan with areas of fieldwalking survey (in light grey) and areas of geophysical survey (dark grey). The modern town of Vasiliko can be seen in the southeast of the map

Initial geophysical work was focused in this latter area with the combined aim of: a) investigating the extent, shape and content of the ancient agora, of which only few monuments have already been known (through excavation), b) trialing different geophysical methods under relatively stable environmental and geological conditions, and c) exploring the relationship between civic centre and wider urban context. Simultaneous fieldwalking survey of tracts (fields) in all three zones outside the agora has further supplemented this initial geophysical work with the introduction in 2006 of magnetic survey of the wider landscape carried out alongside fieldwalking teams.

3 INTEGRATED GEOPHYSICAL SURVEY IN AND AROUND THE URBAN CORE.

Geophysical investigations of the site were initiated by IMS-FORTH at the very beginning of the campaign, in order to cover large sections within and around the ancient agora. Two fluxgate gradiometers, FM256 of Geoscan Research and GRAD 601 of Bardington Instruments, were employed in the high resolution (0.5m sampling) magnetic scanning of the site. A Geoscan Research resistivity meter RM15 with a multiplexer MPX15 and a Twin probe electrode configuration with 0.5 and 1m electrode separation covered large sections of the region. Both datasets were imposed to despiking techniques, grid and line equalization methods, application of different convolution filters, such as high pass filtering or directional derivatives, and histogram stretching methods aiming towards a further enhancement of the resulting maps. In the end, all map products were rectified and imported in a GIS system which was used for the synthesis of the survey results and a diagrammatic interpretation of the geophysical anomalies (Sarris *et al* 2008).

In addition to the two-dimensional mapping of sub-surface relics, an effort was made to calculate the depth and depositional history of selected features. In order to examine their vertical extent, electrical resistivity tomography (ERT) and ground penetrating radar (GPR) techniques were employed. A Sensors & Software EKKO 1000 unit with 225 and 450MHz antennas was used to obtain measurements along parallel lines 0.5m apart, with a 0.05m sampling interval. The results managed to generate a detailed 3D image of specific architectural monuments and suggested that the method could be used to other sections of the site as well. Similarly, a Noggin Plus Smart cart with a 250MHz antenna and a 0.1m sampling was employed for the extensive mapping of areas that imposed problematic conditions of surveying, such as asphalt roads, cement covered parking lots and areas within the wider complex of monumental buildings, some of which were suggested by the conventional prospection methods. (Sarris *et al* 2008).

Three-dimensional ERT data were collected with 2 separate ways. The first one employed measurements of the apparent resistivity along parallel transects using a Syscal Pro ERT unit with a 10 channel multiplexer module (Switch Pro) and a Dipole-Dipole electrode configuration. The second one incorporated two directional (along x- and y-axis) resistivity measurements using the RM15/MPX15/PA5 system of Geoscan Research with a pole-pole array and the modified field procedure of gathering dense parallel tomographies, as it has been described by Papadopoulos, et al, 2006

4 SYNCHRONIZED GEOPHYSICAL AND FIELDWALKING SURVEY OF THE WIDER URBAN CONTEXT.

Outside of the agora teams from the University of York have used fluxgate gradiometer survey (Geoscan FM36) alongside fieldwalking teams. Survey is conducted within the confines of a network of small fields and survey grids of 20X 20m (used also by fieldwalking teams) with a sample interval of 0.5 x 1m provide sufficiently high spatial definition of magnetic anomalies for analysis against surface assemblages. Magnetic survey of these areas benefits from the fact that limestone foundations appear to display good contrast with surrounding soil conditions in most parts of the site.

Limitations imposed by the network of small fields and challenging topography significantly limit the options for suitable sites for magnetic survey across the plateau. In practice, the selection of tracts is largely determined by local field conditions, but the aim of building a balanced representation of the surface/ subsurface relationships across all areas and conditions present on the plateau remains at the forefront of the selection process. Therefore, areas of positive archaeological potential are assigned equal weighing in the selection process to areas deemed of lesser potential.

Survey of this type in the wider urban area has progressed quickly in part because fieldwlaking and geophysical teams work cording to the same spatial framework. Thus far over 70 tracts have been surveyed over all areas of the plateau and a more comprehensive impression of the geological variations, the distribution and physical form of archaeological deposits, and surface topography of the study area is being developed.

5 REPRESENTATIVE RESULTS AND INTERPRETATION

The combined usage of magnetic and soil resistance survey within the area of the agora produced a very detailed plan of the subsurface architectural features of the site, which together with the conserved surface monuments are able to reconstruct the urban center of Sikyon. The council-chamber (*bouleuterion*) and the long stoa, both of which have been partially excavated, have been mapped in detail. GPR measurements along the asphalt road that leads to Vasiliko village and the parking lot that is located to the south of the Roman baths revealed a number of structures that are probably related to a stoa designating the north limits of the agora at a distance of about 120m from the south stoa. The east limits of the agora are defined by the palaistra and a large peristyle building extending for about 62m in the N-S direction, due north of the excavated palaistra complex.

A small tri-partite building, 10 x 6 m, resembling a temple with pronaos and opisthodomos, appears at the center of the complex. The particular feature became one of the targets of the ERT survey mobilizing the RM15/MPX15/PA5 system of the Geoscan and a pole-pole electrode configuration with inter-electrode and inter-line spacing of 0.5 meter and maximum electrode separation equal to $N_{max}=4a$ ($a=0.5$ m). The independent tomographies were combined to produce a reconstructed 3D model that indicates clearly the outline and inner divisions of the structure that seems to extend up to 0.75-1.00 m below the current surface (Sarris *et al* 2008).

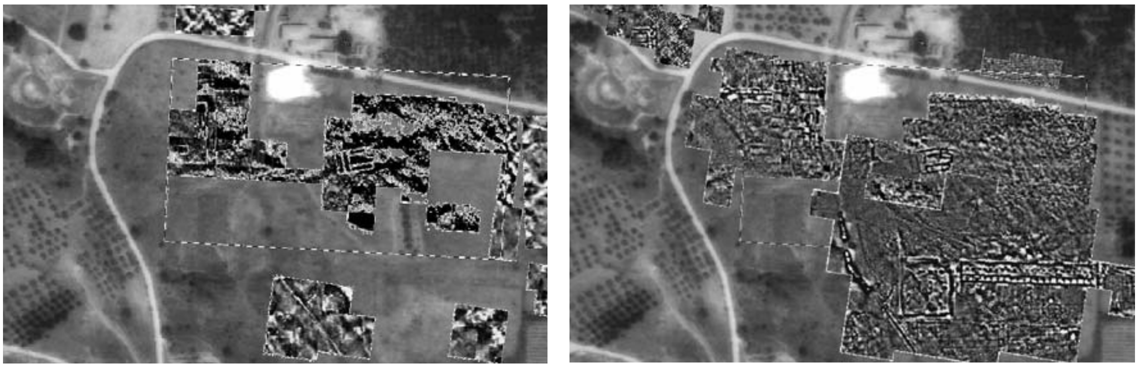


Figure 2. Resulting maps from the soil resistance (left) and vertical magnetic gradient surveys that were conducted in the area of the agora of Sikyon.

Most surprising of all was the discovery of a basilica at the center of the agora. The structure, measuring some 30 by 18m, seems to consist of an inner and outer narthex, perhaps of early Byzantine date, both of which registered well to both magnetic and soil resistance measurements. On the other hand, ERT and GPR slices suggest that the structure was built in two distinct phases that extend within the first 1.5m below surface. The rest of the geophysical anomalies within the context of the agora do not indicate regularity in their provision. In contrast, habitation quarters, structural complexes and a network of orthogonal streets, is suggested by the combined use of magnetic, soil resistance and GPR measurements towards the south and east environs of the agora, suggesting the expansion of the city in this direction. The variable width of the aforementioned streets indicates a hierarchy in the road network of the city, which is still under investigation (Sarris *et al* 2008).

Away from the urban center of the city magnetic survey has proven extremely efficient in providing a geophysical response to synchronized fieldwalking. We now have magnetic survey for over 70 tracts out of a total of 275 covered by fieldwalking teams and coverage is sufficient for initial observations to be made about the archaeological character of certain areas.

Of principal interest in the interpretation of fieldwalking results is the determination of positive building remains and streets of the original city grid. In this regard the contrast in archaeological material between the Upper Plateau and the lower plateaus is striking. From the areas sampled thus far it seems that in the Upper Plateau only the slopes above the agora and theatre contain any significant intensity of land use with areas further to the west and to the south apparently relatively quiet of geophysical anomalies.

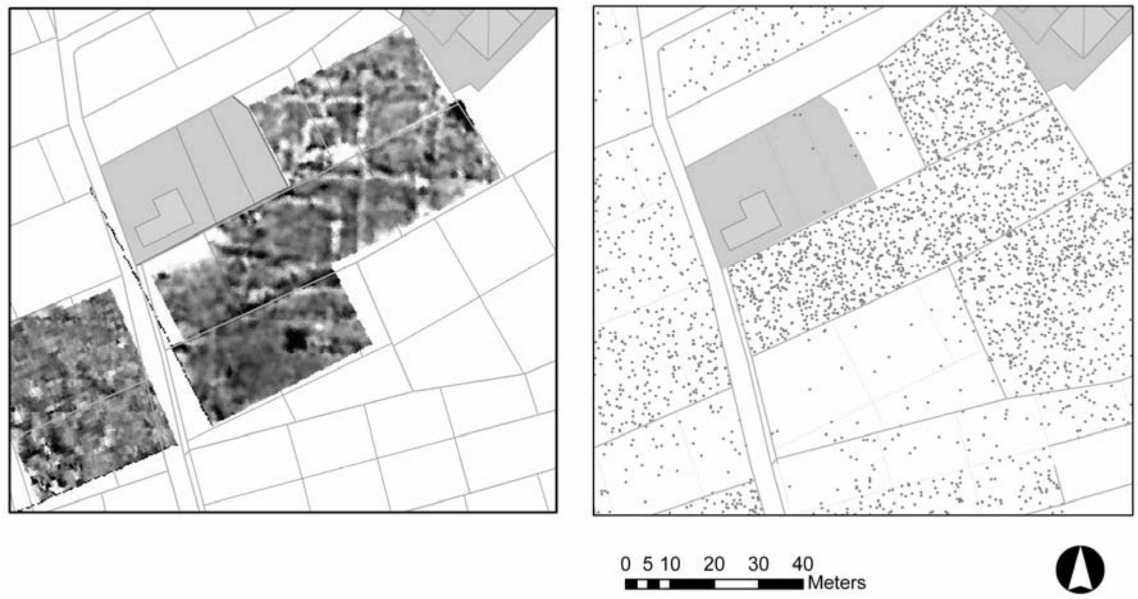


Figure 3. Magnetic survey results from the south Plateau illustrating the orthogonal alignment of many of the limestone foundation of ancient buildings and street shown beside surface distribution plot of ceramic sherds in the same area (1 dot = 10 sherd on the ground).

The observation is confirmed by sherd counts which show a marked reduction from those in other parts of the site. This may reflect a historical zoning pattern in the ancient city where the majority of civic life is concentrated in the south and north with the upper acropolis set aside for agriculture. In contrast, the North and the South plateaus yielded unexpectedly strong responses hinting at high levels of occupation.

Lastly, thanks to the combined geophysical approaches we are able to identify the system of land division and the traces of a formalized town planning at the site. It is now clear that a continuous orthogonal grid was used at least across the North and South plateau (and possibly the upper plateau) and the spacing of streets both on a north/south and an east/west orientation hint at the use of a larger unit of land division in the original layout of the city. The exact layout and form of insulae blocks is gradually being brought to light in various tracts both near the agora and further towards the periphery of the plateau, but initial interpretation of results suggests that while both insula sizes and street widths vary in different parts of the city, both conform to the larger orthogonal geometry outlined above.

6 CONCLUSIONS

Analysis of complimentary surface assemblages in all areas will inevitably lead to a more accurate understanding of the nature and character of such sites. Work on the city grid and its constituent parts is ongoing and further analysis of existing data together with survey in the next two seasons will inevitably refine our appreciation of the physical and historical changes to the ancient city.

Furthermore the combination of geophysical and surface survey at such unprecedented scale, both in terms of geographical extent and intensity of coverage, will provide the means to explore the relationship of surface to sub-surface remains and, ultimately, to evaluate the reliability of surface survey as a whole.

7 REFERENCES

Lolos, Y., Gourley, B, Stewart, D. 2007. "The Sikyon Survey Project: A Blueprint for Urban Survey?" *Journal of Mediterranean Archaeology* 20, 267-296.

Papadopoulos, N. G, Tsourlos, P., Tsokas, G. N., Sarris A. 2006. Two-dimensional and three-dimensional resistivity imaging in archaeological site investigation. Archaeological Prospection, 163-181.

Sarris, A., Papadopoulos, N., Trigkas, V., Kokkinou E., Alexakis, D., Dimitrides, D., Kakoulaki, G., de Marco, E., Seferou, E., Aresti, G., Shen, G., Kondili, F., Karaoulis, M., Karifori, M., Simiridanis, K., Koustas, G., Nikas-Karayiannis, Y., Dogan, M., Stamatis, G., Kappa, E., Lolos, Y., Kalpaxis, Th. 2008. Recovering the Urban Network of Ancient Sikyon Through Multi-component Geophysical Approaches, *Proceedings of the International Conference of Computer Applications in Archaeology: Layers of Perception (CAA2007)*, Berlin, Germany, *in print*

Quantification of buried slag volumes by using non-invasive geophysical methods

N. Florsch[1,4] , M. Llubes[2], F. Téreygeol[3], A. Ghorbani[1], P. Roblet[2]

1 UMR 7619 "Sisyphe", Université Pierre et Marie Curie, Case courrier 105, 4 place Jussieu,75252 Paris Cedex 05, France, nflorsch@gmail.com

2 Observatoire Midi-Pyrénées, Toulouse, France, muriel.llubes@gmail.com

[3] CNRS and CEA, Belfort, France, florian.tereygeol@cea.fr

[4] UMMISCO, Institut de Recherche pour le Développement, Cape Town, South Africa

Keywords: archaeometallurgy, slag, smelter, induced polarization, Castel-Minier

ABSTRACT.

The geophysical methods as used for archaeological purpose are often useful for the search, detection and mapping of archaeological remains. As far as metallurgical activities are concerned, slag accumulations form precious mineral records of ancient metallurgical activities. Estimating the volume of produced slag is an important issue since it leads to estimates of the amount of metal produced in the smelter. Unfortunately, slags themselves cannot be detected by DC electrical methods. Altough they can be easily detected by using magnetic methods, those do not permit one to derive the quantity of slags, as magnetic fields do not conserve magnetic flux.

In this work we show that the Induced Polarization method (IP) is suited to the quantification of buried slags, provided that a calibration has been previously performed. It lies on the quasi linear relationship between the main IP parameter, i.e. the chargeability, and the slag concentration. This provides a new method to estimate the volume of buried slag in paleometallurgic sites by non invasive tools.

An application is shown at Castel Minier site, Ariège, France.

1 INTRODUCTION

Slags make up one major remain of ancient metallurgical activity. Hence, quantifying slag heap is an important issue for archaeology, since it is a good indicator of the produced metal.

In the field of the geophysical methods used for archaeological research, the magnetic survey is considered as the most powerful to reveal ancient metallurgical activities. Its ability to detect furnaces, smelters, makes it a precious tool for archaeologists and archaeometallurgists. By measuring the magnetic field just above the ground surface, this method also permits to delineate buried slag accumulations. Unfortunately, the magnetic field presents a mathematical feature that definitively prevents any amount estimation (at least without additional hypothesis): this is because its flux is not conservative. Indeed the magnetic field due to an elementary dipole decreases as the cube of the distance, while the surface crossed by the field depends on the square of the distance. It results in the fact that, except if one knows the distance to the magnetic source (its depth), it will never be possible to find out the quantity of buried slags, since the flux is the only quantity which permits mass estimation from the surface. Susceptibility methods are also useful to delineate concentration of slags close to the surface, but falls to provide suitable information on the depth and quantity of buried slag accumulation.

It is often admitted than slags do not lead to specific geophysical response except magnetics. However, in the present paper we expound and demonstrate the ability of the Induced Polarization method to retrieve the geometry and amount of buried slag accumulations. Although it is done here for ferrous slags, other results (not shown here) let us hope it works also well for non ferrous metallurgies.

2 THE INDUCED POLARISATION METHOD

The Induced Polarization method (IP) is related to electrical methods: most of the concepts, arrays, inversion schemes in use in electrical methods can be extended to IP. The IP method consists in measuring the complex impedance of the ground as a function of time (it is the “classical method”) or frequency (that is the Spectral Induced Polarization “SIP”) instead of the single resistivity. The later can be considered as the real part of the IP response at the null frequency (or its continuous component).

While employing the classical IP method, a DC generator first injects a constant current into the ground, then the current is suddenly shut down. However the potential at the receiving electrodes doesn't vanish immediately. Let's notice V_0 the voltage before the cut off; just after the cut, the potential is V_1 and later decay with a more or less exponential behavior. This occurs because some material in the ground remains polarized, that is carries electrical dipolar properties (due to the fact that positive and negative electrical charges are slightly separated by the imposed initial electrical field). Practically, an alternative squared current is used to eliminate spontaneous polarizations. Alternatively, by using the frequency domain, the current is controlled to be sinusoidal. The receiver measures the amplitude and phase of the resulting potential. The two methods can be linked by using signal theory (Fourier and/or Laplace transforms). Measuring IP is actually measuring the complex transfer function of the ground. Practically, the frequency approach is richer than the temporal one, but harder to realize on the field. Numerous physical phenomena can be involved in the IP, but cannot be detailed here. The reader could refer to the historical work of Luo & Zhang, 1998.

As a first approach, one can consider that the IP response is related to a simple general linear relaxation phenomenon, leading to an exponential decay: this is Debey's model. After the cut-off, the potential is written: $V(t) = V_1 e^{-\frac{t}{\tau}} = V_0 \frac{V_1}{V_0} e^{-\frac{t}{\tau}} = V_0 m e^{-\frac{t}{\tau}}$. The parameter (m) is called the chargeability. It is without dimension but is homogeneous physically speaking to the concentration of particles responsible of the polarization. The parameter (τ) is a time constant. When generalizing Debye's model, one may involve a continuous spectrum of time constants and chargeabilities. This led to an important set of possible transfer functions, as described in the literature, the most known being Cole-Cole's model (see for example Dias, 2000). Temporal apparatus generally provide the quantities also called chargeability but having the dimension of the time: $M_{a,b} = \frac{1}{V_0} \int_{t_a}^{t_b} V(t)dt$ where the integral of integration is a matter of choice. Numerous other quantities are in use, depending on habits.

Most of the materials can be polarized but generally show a small chargeability and a small time constant (saying less than 1 msec). However some minerals show huge responses, notably when some particles with metallic conductivity are present. That's why the IP method is a major (and historical) geophysical tool to detect disseminated sulfur ore bodies. Graphite and even magnetite show high IP responses. That is the expected presence of sulfur or magnetite or any other polarizable mineral that lead us to test IP for slag detection and contouring (see Schön, 2004 for a digest on IP material responses).

Although the time constant and some additional parameters of models more sophisticated than Debey's one are of great interest to identify the minerals responsible of an IP response, we focused in a first approach to simple goals:

- to show that the chargeability (m or M) is a simple function of slag concentration;
- to show an example on the field that illustrate the ability of IP to quantify buried slags.

We make use of data from the site of Castel-Minier which was the most important silver mine during the second part of the 14th Centtury (Bonnamour *et al.*, 2007).

3 THE IP RESPONSE OF SLAGS

3.1 *First insight on the field*

Notice that IP response must be measured by using non polarizable electrodes. We made use of the $Cu/CuSO_4$ couple (for field and lab experiments).

During a first campaign, we measured the IP along a unique profile by using the frequency method. It showed effective response over two known slag pockets (previously seen by magnetic survey and later confirmed by excavating). Spectral responses have been inverted by using a Cole-Cole inversion scheme and this insured us that the time constant related to slags is at least greater than 200 msec. Following that we made use of time domain IP, just measuring partial chargeability M_1 (as an output of the Terrameter ABEM used here). We preferred time domain to do this first mapping experiment since the spectral method is much more time consuming. M_1 is the integral of the potential decay between to time t_1 and t_2 (between 10 ms and 30 ms in our case). As far as t_2 is much smaller that the time constant, that is: $t_1 < t_2 << \tau$, then one can show that: $M_1 \cong m(t_2 - t_1)$ and then derive (m). Although the retrieving of τ is of great interest since it should permit to discriminate between various material, it is dropped here because it is not required to provide slag concentration.

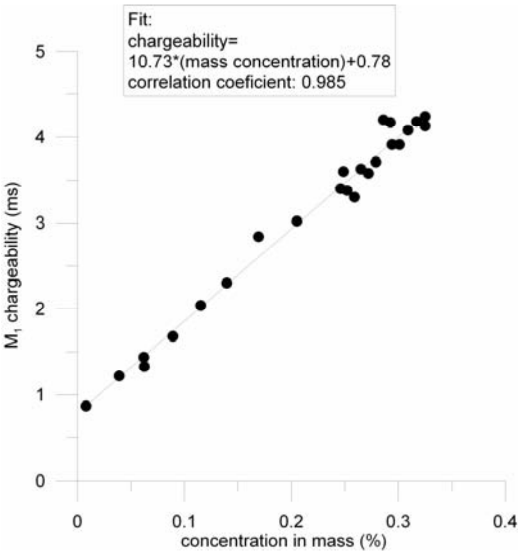


Figure 1. Experimental relationship showing the affine dependence between slag mass concentration and instrumental chargeability as obtained by tank laboratory procedure

3.2 *Laboratory experiment*

Following that first field experiment, we developed measurements on soil and slag samples. In a tank with an appropriate disposal and array, we used a mass controlled mixture of slags and local soil (the later initially free of slag). Figure 1 shows the affine relation we get, leading to that first conclusion: as expected, M_1 behaves linearly with respect to the slag concentration. Of course, the exact constant of this affine relation is expected to change depending on the kind of polarizable material. Once a calibration has been done, one can convert the partial chargeability (M_1) in (m) or directly into slag concentration.

3.3 *Slag heap ip tomography on the field*

Classical electrical tomography ("ERT") permits to map a vertical section or even a 3-D repartition of the ground resistivity. In the same way, measuring IP permits to map the chargeability. Actually the simplest way to deal with IP modeling and inversion consists in adding a complex part to the apparent resistivity (Loke, 2006). Hence, ERT and IPT (IP Tomography) can be issued of the same measurement sequence. The upper part of the Figure 2 shows the resistivity map and the ERT, while the lower part shows the chargeability response with the same geometry. As usual, the electrical images are related to the water/electrolyte and clay contents and no specific response can be linked to the buried slag heap. At the opposite, the IP map and tomography show a very confined and well-shaped anomaly. Further archaeological excavations permitted to verify that these IP images are fully in accordance with slag accumulations. The association of lab experiments, field IP measurements and excavation results show clearly the ability of the IP method to detect and to quantify buried slag heaps with the same resolution than electrical methods do for confined resistive or conductive bodies. Furthermore, the chargeability (m or M_1) can be converted in mass concentration, and the later can be integrated over the area to provide the total slag mass. However this would require a full 3-D investigation like a set of equally spaced ERT sections. Ones the calibration done, that is ones we have obtained the constants (α,β) linking the chargeability and the mass concentration by lab calibration, saying, like in Figure 1: $M_1^{calib} = \alpha C^{calib} + \beta \Rightarrow C(x,y,z) = \dfrac{M_1(x,y,z) - \beta}{\alpha}$

(note: the left term is the calibration, the second term is the field 3-D data), the total mass of slag is derived from a simple 3-D numerical integration (over model cells) of the chargeability 3-D inversion.

More precisely:

Total mass of slag $= \rho_{slag} \iiint_{prospect} C(x,y,z)dxdydz$.

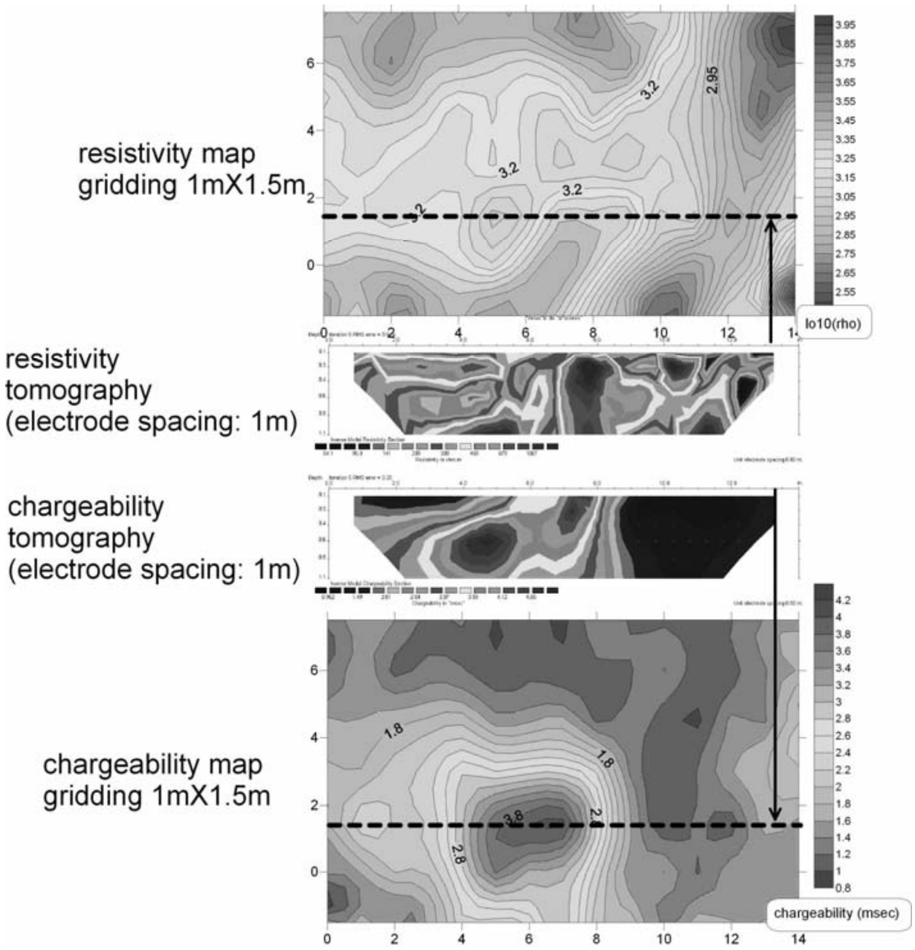


Figure 2. Electrical map and section (the two top figures) and IP map and section (the t wobottom figures)at castel-Minier (Ariège France) showing the ability of the IP method to quantify buried slags

4 CONCLUSION

From these first elements as provided by these experiments, it appears that the induced polarization method would be an efficient and suitable geophysical tool which would permit to estimate the quantity of buried slags on ancient metallurgic sites (and hence to derive the quantity of produced metal while a full excavation politic cannot be undertaken). Since this is a very new issue, it must be confirmed by larger investigations (including full 3-D campaigns) and a minimum set of various case studies.

5 REFERENCES

Bonnamour, G., Florsch, N., Téreygeol, F. 2007. Les prospections des ferriers de Castel-Minier: approche interdisciplinaire. *Archeosciences, revue d'Archéométrie*, 31: 37-44.

Dias, C. A. 2000. Developments in a model to describe low-frequency electrical polarizationof rocks*, Geophysics*, 65(2) : 437-451.

Loke, M.H., Chambers, J.E. Ogilvy, R.D. 2006. Inversion of 2D spectral induced polarization imaging data*, Geophysical Prospecting*, 54 : 287–301.

Luo, Y., Zhang, G. 1998. *Theory and Application of Spectral InducedPolarization,* Geophysical Monograph Series.

Schon, J.H. 2004. *Physical Properties of Rocks: Fundamentals and Principles of Petrophysics*. Pergamon Press, ISBN-10: 008044346X, ISBN-13: 978-0080443461

On the application of near-surface temperature investigations for delineation of archaeological targets

L. V. Eppelbaum
Dept. of Geophysics and Planetary Sciences, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Ramat Aviv 69978, Tel Aviv, Israel, E-mail: levap@post.tau.ac.il

Keywords: archaeological remains, thermal properties, near-surface survey, quantitative analysis

ABSTRACT:
An essential principle of geophysical methods application at archaeological sites is difference of physical characteristics between the ancient remains and surrounding medium. Majority of archaeological objects – industrial, agricultural and weapon targets, cultural and worship pieces, many remains of ancient constructions, etc. – have contrast (comparing with the host media) thermal properties. Thus, temperature near-surface measurements (in small boreholes at the depth of 1-1.5 m) can contain useful and sometimes unique information about the ancient objects occurring at small depths below the points of observations. At the same time, near-surface temperature survey is very rarely carrying out at archaeological sites. It was caused by few reasons most important from which is the noise caused by seasonal temperature variations propagating with some delay from the earth surface to the points of observations. Other disturbing factor is terrain relief effect significantly distorting the observed temperature field. Finally, analysis of temperature anomalies during the long time was limited by the absence of efficient quantitative procedures for temperature field examination.
The developed interpretation scheme includes: (a) elimination of seasonal temperature variations by the use of linear filtering with utilization of repeated temperature observations and data of meteorological stations in the vicinity of the area under study, (b) calculation of terrain relief influence by a correlation technique, which facilitates the identification of anomalies associated with concealed geological features, (3) effective interpretation scheme of temperature anomalies observed under complex environments. The last item is based on the essential similarities between thermal and magnetic fields make it possible to apply to thermal prospecting improved modifications of characteristic points, tangents and areal methods developed for magnetic prospecting. These methods are applicable to conditions of inclined relief, arbitrary magnetization (polarization), and an unknown level of the normal field. Interpretation is made possible by approximating bodies by a thin inclined bed and a horizontal circular cylinder. In order to classify the intensity of a thermal anomaly is suggested to use a "temperature moment", equivalent to the "magnetic moment" used in the magnetic prospecting. Employment of temperature surveys at different depths will help to obtain additional valuable information about the near-surface targets (depth, size, and configuration as well as thermal properties). Additional interpretation tool is calculation of horizontal and vertical temperature field derivatives. The interpretation results obtained both on models and in real situations testify to the accuracy and reliability of these methods. For increasing an effectiveness of buried archaeological remains localization and their classifying is suggested to integrate the near-surface thermal prospecting with other land geophysical surveys and the remote operated vehicle thermal infrared inspection.

1. INTRODUCTION

Near-surface thermal prospecting is based on temperature measurements in shallow (1-1.5 meters depth) drill holes. Taking into account differentiation of archaeological objects by their thermal properties, such temperature measurements contain useful information about ancient remains in the sites under study. It should be underlined that studying of thermal parameters in archaeological prospection sometimes may play no more important role than conventional geophysical methods (GPR, magnetic, EMT, etc.) (Eppelbaum, 2000).

At the same time, the noise caused by seasonal temperature variations and terrain relief effects may significantly distort the temperature anomalies observed in the near-surface layer (Eppelbaum & Khesin, 2001). The main aim of this paper is to attract attention to processing and interpretation methods allowing to eliminate the noise background and to obtain some quantitative parameters about buried archaeological targets.

2. ELIMINATION OF NOISE FACTORS

2.1. Elimination of Temporary Temperature Variations

Various methods of geothermal surveying and data processing have been developed for eliminating the temporary variations of temperature. The procedure suggested by Parasnis (1971) speeds up the field works but does not allow to remove seasonal variations. Other method consists of conducting a long-term geothermal investigation of the area under study and selecting a period when seasonal variations are minimal for the field survey (Dobrynina *et al.*, 1985). However, this method suffers from such drawbacks as long duration, and hence nonapplicability of the results, since the time of fieldwork is frequently set by organizational factors, etc.

Two other methods are worth mentioning: (1) synchronous measurement of the temperature variations within the field survey (Khutorsky *et al.*, 1983) similar to the well-known method of eliminating magnetic field variations in magnetic prospecting; (2) measurement of the temperature simultaneously at all points of the profile (Chekalyuk *et al.*, 1974). However, in the first method it is not always possible to avoid the influence of temperature waves delayed in diffusing from the surface. The second method (it should be noted that we do not sure that such a procedure allows to remove all temporary variations) demands simultaneous use of many temperature-measuring devices which impede the surveying.

A method for eliminating temporary variations using repeated observations with subsequent linear filtering of the results was suggested by Eppelbaum & Mishne (1988). It is known that a regional thermal field is stable in time (Lubimova, 1968) and temperature-wave propagation in the medium is linear (Tikhonov & Samarsky, 1963). Taking into consideration these factors, a model of the total temperature field, recorded in the layer with annual temperature oscillations, can be represented in the following form:

$$Q_i = T_i + \sum\nolimits_{j=t-t'}^{t} \tau(j) f(t-j), \tag{1}$$

where $Q_i(t)$ is the observation at the ith point (borehole); T_i is the temperature conditioned by redistributing the deep heat flow caused by the object with contrasting conductivity; $\tau(j)$ is the average temperature at a certain depth Δh at time j along the region including the district under investigation (data from meteorological stations are employed); $f(t\text{-}j)$ is the weight step function reflecting the temperature effect at the depth Δh, at time $t\text{-}j$ on the temperature measured in the borehole, at depth h at time j; and t' is the delay time of temperature waves diffusing down the surface.

Measurements at the observation points made at different times t enable one to obtain a solvable set of algebraic equations that allow the desired signal T_i to be extracted with the required accuracy (Eppelbaum, 1999).

2.2. Elimination of Terrain Relief Effect

It should be pointed out that the terrain relief effect is generally twofold (Khesin et al., 1996). First, the form and physical properties of topographic masses (e.g., rocks forming the relief) condition the presence of their effects in the anomalous field, which dampens the anomalous effects from the hidden objects to be prospected. Second, uneven observation lines are responsible for variations in the distance from the point of measurements to the source, and these variations manifest themselves differently in the anomalies from different objects. Therefore, in the general case it is necessary to calculate and eliminate the topographic effect from the observed field and to reduce the observation results to a common horizontal level (usually the highest point of the relief). Moreover, to solve a direct geophysical problem one has to know the physical properties of the geological (archaeological) targets, so upward continuation can be used to reduce the anomaly under study.

The principle of this technique consists of constructing a correlation between the field values (U) and the heights of observation points (H) in the middle part of the slope, followed by determination of regression coefficients α and β. Thus, we obtain the approximate linear relationship

$$U_{\text{appr}} = \alpha + \beta H. \tag{2}$$

The value U_{appr} is subtracted from the field value U observed at every point with the known height H. Thus, we obtain the corrected field value U_{corr}, which may reflect presence of some desired archaeological remain.

The inverse dependence of the surface temperature on the height of observations was pointed many investigators. A comparison made between the plots of the vertical magnetic field component (at vertical magnetization I) and the relative heat flow q/q_0 indicates their complete inverse correlation. This allows us to employ the correlation method for processing of near-surface temperature survey performed under conditions of rugged terrain relief.

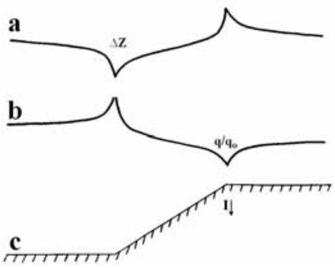


Fig.1. Comparison of plots of (a) the magnetic field vertical component Z, and (b) relative heat flow q/q_o over (c) a slope in terrain (the curve (b) is from Lachenbruch (1968))

3. QUANTITATIVE INTERPRETATION OF TEMPERATURE ANOMALIES

Carslaw and Jaeger (1959) noted that the problem of the disturbance of steady linear flow of heat in a uniform medium by an object of different conductivity is precisely the same mathematically as that of induced magnetization in a body of the same shape placed in a uniform external field.

After removing the seasonal temperature variations, which affect the stationary temperature field, we can write the standard Laplace equation $\nabla^2 T = 0$ (T is the temperature). The right side of expression (1) is simplified correspondingly, leaving only the value T_i.

Under stationary thermal conditions, heat propagation via conduction in solid bodies follows Fourier's law:

$$\vec{q} = -\lambda \,\mathrm{grad} T, \tag{3}$$

where $\vec{q}$ is the thermal flow and λ is the thermal conductivity.

The magnetic field is also potential (Poisson equation) when the value of the magnetization is below 0.1 SI unit (Khesin *et al.*, 1996):

$$\vec{U}_{an} = \mathrm{grad} V, \tag{4}$$

where $\vec{U}_{an}$ is the anomalous magnetic field, and V is the magnetic potential.

It is obvious that expressions (3) and (4) are proportional.

In the magnetic prospecting were developed methods for magnetic anomaly quantitative interpretation (improved modifications of tangent and characteristic point methods) under complicated environments (Khesin et al., 1996): rugged terrain relief, arbitrary magnetization and unknown level of the normal field.

A disturbing object model in the form of a sphere or horizontal circular cylinder (HCC) is rather frequently used in thermal prospecting (Carslaw & Jaeger, 1959; Kappelmayer & Haenel, 1974). The anomalous effect of a homogeneous sphere does not depend upon its volume; therefore, when volume and thermal conductivity are not of fundamental importance, a material point may be substituted for a model of the sphere.

The analytical expressions for geothermal and magnetic (vertical component Z) fields are presented in Table 1.

Analytical expression for	Magnetic field	Temperature field
Point mass (magnetics) Sphere (geothermics)	$Z = \dfrac{mz}{(x^2 + z^2)^{3/2}}$ (5)	$T = {}^{q}\!/_{\lambda_{an}} \left[(1-\mu)/(2+\mu)\right]\left[R^3/(x^2+z^2)^{3/2}\right]$ (6)
Thin bed (magnetics) HCC (geothermics)	$Z = 2I2b\dfrac{z}{(x^2 + z^2)}$ (7)	$T = {}^{q}\!/_{\lambda_{an}} \left[(1-\mu)/(1+\mu)\right]\left[C^3/(x^2+z^2)\right]$ (8)

Table 1. Comparison of some analytical expressions for models employed in magnetic and temperature fields

where m is the magnetic mass, I is the magnetization, and b is the half-width of the thin bed's upper edge, μ is the body-medium thermal conductivity ratio, R is the radius of sphere, C is the radius of HCC, z is depth of sphere (HCC) center, and x is the running coordinate.

The proportionality of the expressions (5) and (6), (7) and (8), respectively, is evident.

Fig. 2 shows the comparison of magnetic (a) and temperature (b) anomalies from an inclined thin bed (rod) and the results of their quantitative interpretation. The ΔZ anomaly has been computed, while the temperature anomaly has been obtained by physical modeling. Both geophysical anomalous graphs and results of their analysis are similar ones.

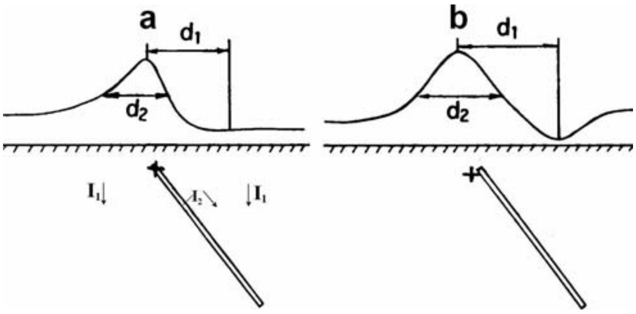


Fig.2. Comparison of magnetic (a) and temperature (b) anomalies over a model of an inclined thin body. The arrows show the direction of the magnetization vectors I. The "+"symbol marks the position of the upper edge of the thin body, as obtained from analysis of the anomalous graphs.

In order to classify the intensity of a thermal anomaly is suggested to use a "temperature moment", equivalent to the "magnetic moment" used in the magnetic prospecting (Eppelbaum et al., 1996).

The preliminary testing of the presented interpretation system testifies to applicability of the methodology for identification of buried archaeological remains, especially in the archaeological sites with high levels of magnetic/electromagnetic noise. At the same time all accomplished archaeogeophysical experience indicates that the method should be integrated with the remote operated vehicle thermal infrared inspection or some types of land geophysical surveys (Eppelbaum et al., 2008).

4. CONCLUSIONS

To reveal a stable geothermal anomaly that can be interpreted quantitatively, effects caused by time variations of temperature and influence of terrain relief must be eliminated from the observed temperature field. Techniques developed for this purpose include repeated geothermal observations at instants of time chosen to eliminate temperature variations. Correlation between observed fields and observation point heights is a technique used for reducing the effect of terrain relief.

The applicability of methods of magnetic anomaly interpretation, which are thoroughly developed for complicated models including rugged relief, inclined polarization and unknown level of the normal field, to models in thermal prospecting is substantiated on the basis of some common aspects of magnetic and temperature potential fields. It makes possible to productively use the near-surface thermal prospecting for recognition and delineation of buried ancient remains. The preliminary testing indicates that integrating method with the remote operated vehicle thermal infrared inspection (or some types of land geophysical survey) will increase its effectiveness.

5 REFERENCES

Carslaw, H.S., Jaeger, J.C. 1959. *Conduction of Heat in Solids*. Oxford Univ. Press.

Chekalyuk, E.B., Fedortzev, I.M., Osadchy, V.G. 1974. Geothermal Field Survey, Naukova Dumka (in Russian).

Dobrynina, Z.K., Dmitrieva, T.A., Pletnev, A.A., Semenov, V.G., Skornyakov, S.M. 1985. Shaping of seasonal thermal anomalies over ore bodies, *Izvestiya.VUZOV*, *Ser. Geol. and Prosp.*, 8: 98-101 (in Russian).

Eppelbaum, L.V. 1999. Near-surface thermal prospecting in petroleum geology, *In*: *Applied Geothermics for Petroleum Engineers*, Elsevier: 274-301.

Eppelbaum, L.V. 2000. Applicability of geophysical methods for localization of archaeological targets: An introduction, *Geoinformatics*, 11, No.1: 19-28.

Eppelbaum, L.V., Khesin, B.E. 2001. Disturbing Factors in Geophysical Investigations at Archaeological Sites and Ways of Their Elimination, *Proceed. of the IV Conf. on Archaeological Prosp.*, Vienna, Austria: 99-101.

Eppelbaum, L.V., Khesin, B.E., Itkis, S.E. 2008. Archaeological geophysics in arid environments: Examples from Israel, *Journal of Arid Environments* (in Press).

Eppelbaum, L.V., Mishne, L.R. 1987. Quantitative calculation of seasonal temperature variations in near-surface thermal prospecting (in Russian), *Trans. of the All-Union Conference "Means for Improving the Effectiveness of Geophysical Methods"*, Moscow, USSR: p.54.

Eppelbaum, L.V., Modelevsky, M.M. (Jr.), Pilchin, A.N. 1996. Thermal investigation in petroleum geology: the experience of implication in the Dead Sea Rift zone, Israel. *Jour. of Petroleum Geology*, 19(4): 425-444.

Kappelmayer, O., Haenel, R. 1974. *Geothermics with Special Reference to Application*, Borntraeger.

Khesin, B.E. and Eppelbaum, L.V. 1994. Near-surface thermal prospecting: Review of processing and interpretation, *Geophysics*, 59(5): 744-752.

Khutorsky, M.D., Salnikov, V.E., Fotogdinov, R.A. 1983. Geothermal prospecting of ore deposits, In: (Eds. Kropotkin, B.M. and Smirnov, Ya.B.), *Methodical and experimental principles of geothermometry*, Nauka: 212-229 (in Russian).

Lachenbruch, A.N., 1968. Rapid estimation of the topographic disturbance to superficial thermal gradients. *Rev. Geophys.*, 6 (3): 365-400.

Lubimova, E.A. 1968. Thermics of the Earth and Moon, Nedra (inRussian).

Parasnis, D.S. 1971. Temperature extrapolation to infinite time in geothermal measurements. *Geoph. Prosp.*, 19: 612-614.

Tikhonov, A.N., Samarsky, A.A. 1963. *Equations of Mathematical Physics*, Pergamon Press.

Application of the Holographic Radar RASCAN to Cultural Heritage Inspection

L. Capineri[1], P. Falorni[1], G. Borgioli[1], T. Bechtel[2], S. Ivashov[3], A. Zhuravlev[3], M. Paradiso[4], G. Cartocci[4].

1 *Ultrasound and Non Destructive Testing Laboratory, Dept. of Electronics and Telecommunications, University of Florence, 50139, Firenze, Italy, capineri@ieee.org*

2 *Dept. of Earth & Environmental Sciences, University of Pennsylvania, Philadelphia, PA 19104, USA, bechtelt@sas.upenn.edu*

3 *Remote Sensing Laboratory, Bauman Moscow State Technical University, Research Institute of Applied Mathematics and Mechanics, Moscow, 105005, Russia, sivashov@rslab.ru*

4 *Dept. of Constructions, University of Florence, 50121, Firenze, Italy, paradiso@dicos.unifi.it*

Keywords: subsurface radar, non-destructive testing, holographic imaging, crack detection, moisture detection, void detection

ABSTRACT.

This paper explores the application of holographic radar for cultural heritage investigations. The application is demonstrated by the analysis of a decorative marble plate on the floor of the Temple of San Biagio in Montepulciano, Italy. RASCAN is the brand name of an holographic subsurface radar that has been developed for landmine detection and sounding of building construction details, and here is used for the first time for the survey of a suspected burial place beneath the marble stone. Several laboratory experiments are also reported to demonstrate and explain the capabilities of this new type of Radar for cultural heritage investigations.

1 HIGH SENSITIVITY OF HOLOGRAPHIC RADAR TO SMALL WATER CONTENT AND SUBSURFACE PROPERTIES.

The holographic images produced by the new RASCAN subsurface radar are very sensitive to shallow variations in electromagnetic properties of the materials under investigation. The sensitivity of the RASCAN technology is demonstrated experimentally and the results reported below. The radar used in this study is a RASCAN-4/4000 which operates at five discrete frequencies in the band of 3.6-4.0 GHz, with two simultaneous antenna polarizations for each frequency. The radar has a small scanning head that is moved by hand.

Figure 1 shows the capability of detecting of a tight, almost invisible, crack in a granite slab that is even more evident when the crack is wet (since the relative permittivity of water is 80 and that of granite is 5). The sensitivity to water content at the 4 GHz signal frequency is very high; this is demonstrated also with a very little amount of moisture in marble as shown in the experiment in figure 2. Finally, due to the small wavelength at this high frequency (about 3 cm at 4 GHz in travertine) small size cavities can be detected with high spatial resolution imaging (see figure 3). In Figure 3, a slab of travertine was scanned on its polished side (reverse side – not shown in this figure). From the polished side, it is clear that there are vesicles (large pores) in the stone, but they are filled with some type of cement or grout. Scanning of the polished side reveals many diffractors or targets within the stone, that are visible upon inspection of the back side (unpolished – see photos). In particular, the large pore at the upper left is quite apparent. This pore was dampened with several drops of water (lower left picture), and the slab re-scanned. The moisture makes a very strong diffractor on the radar image (lower right).

2 INVESTIGATION OF A MARBLE MEDALLION

An application to a real historical structure was performed by scanning a decorative marble medallion in the floor of the Temple of San Biagio in Montepulciano, Italy. RASCAN radar images of the marble medallion reveal a complex structure of the medallion, the origin of which is not clear without additional information. Through our experiments, we have tried to best interpret the radar images, with the help of an accurate relief and historical information.

The spatial correlation between the optical and the RASCAN image (see Figure 4, center and right) is very high, as overlay of the two images (Figure 4, right) shows. With certainty we can affirm that the contrast obtained in the radar image has dielectric nature and is non-metallic, and we can formulate hypotheses for interpretation of three contrast patterns enclosed by yellow boxes.

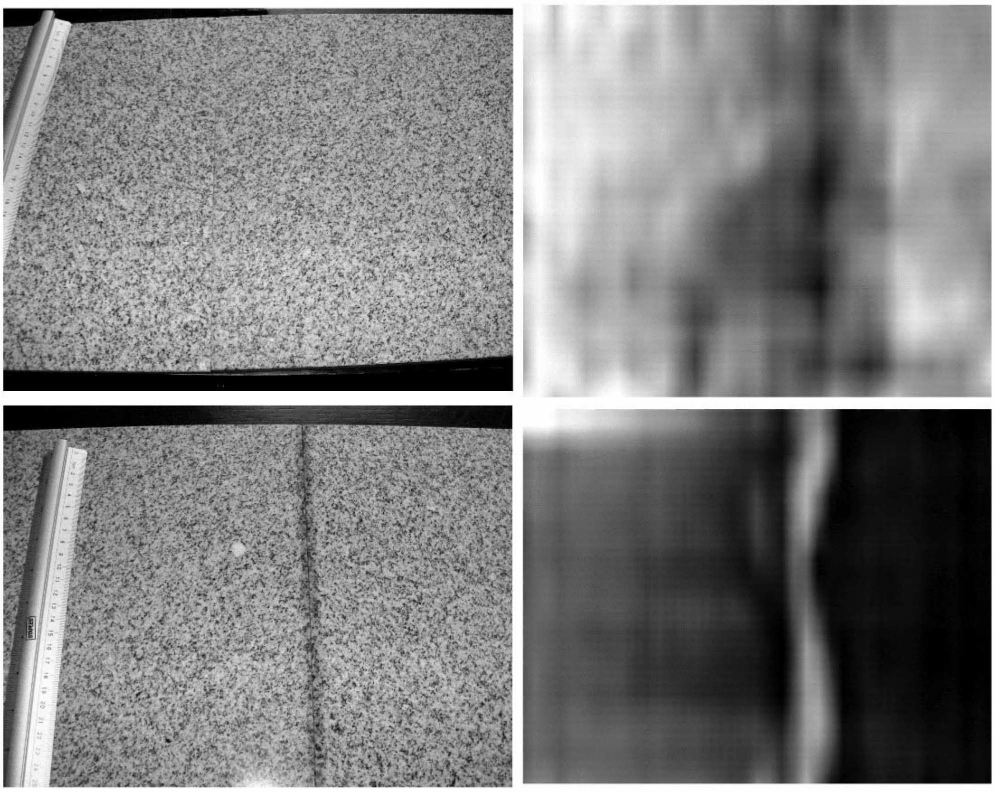


Figure 1. A tight-fitting crack in a granite slab was scanned dry (top), and again after dampening with tap water (bottom). For both scans, the cracked slab was covered by a second intact granite slab with thickness of about 6 mm. The crack is clearly seen in both wet and dry conditions, but is more distinct when wet. The images are 25 cm by 40 cm.

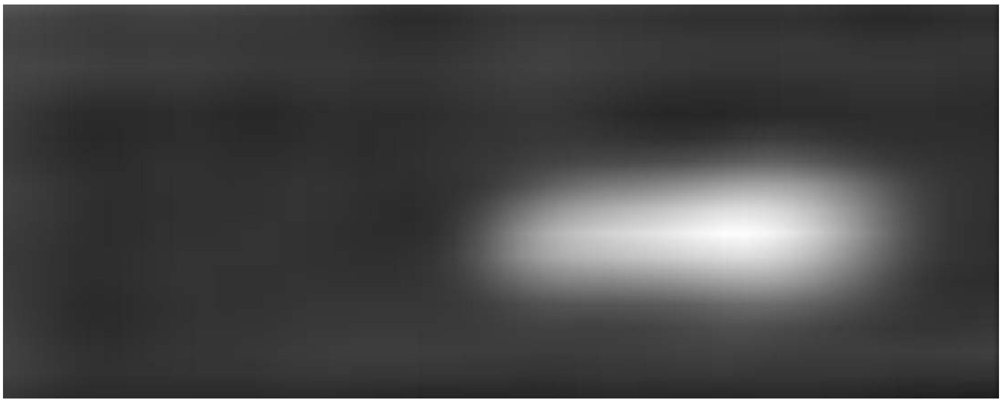


Figure 2 Two drops of water were placed on the unpolished back of a marble slab with thickness of about 12.5 mm. The water immediately soaked into the stone. The slab was flipped over and scanned on its polished surface, where no moisture was visible. The damp spot on the back side is clearly shown in the 25 by 45 cm radar image.

Vertical contrast patterns 1 and 2 may represent the presence of two rows of bricks or wooden beams supporting the marble medallion. The third contrast pattern (tilted box at the base of the image) is visible in the optical image as a subtle discolored line on the marble, and could be explained by the presence of moisture along a fine crack, or other wooden or brick elements beneath the medallion.

According to an historical investigation, which we found to contain information about the medallion, the presence of Vincenzo Cervini's burial in this location is quite sure. So, we can formulate a reasonable assumption that results from the combination of the RASCAN image and minor historical research. Probably under the marble stone there is a small vault or void with some bricks or wood to support the medallion. These elements may lie on top of a curved surface forming the roof of the burial place. Thanks to the high spatial resolution of this type of radar resulting from signal phase detection of the multiple discrete frequency continuous waves, it is possible to detect subtle features in the image, such as reflections from curved surfaces or small changes in the dielectric properties of materials.

3 AN INTERPRETATIVE MODEL AND FINAL OBSERVATIONS

In order to sustain the above interpretation of what was discovered under the marble medallion by holographic imaging, a simple laboratory model that mimics the proposed situation has been developed. A granite slab was placed on two terracotta bricks, and scanned with the RASCAN. The two bricks show clearly behind the granite (Figure 5). For this experiment, all materials were dry, and the image is 25 cm by 30 cm. As shown in Figure 5, RASCAN radar has the capability of detecting the brick supports, and produces an image that supports our hypothesis that under the marble stone there is a void with wood or brick elements supporting the medallion.

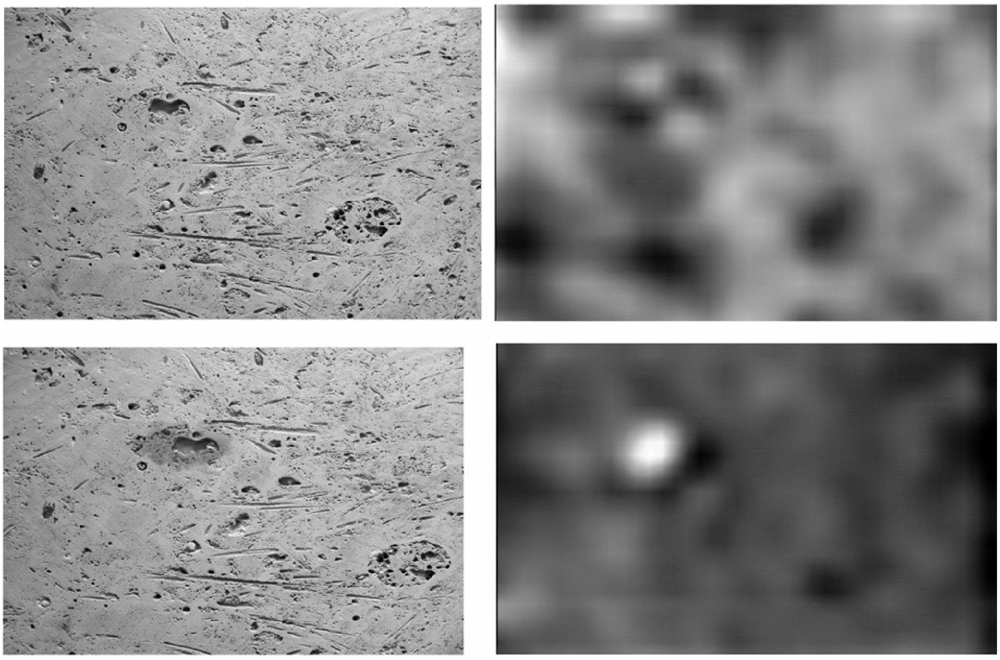


Figure 3. Scanning was performed on the reverse (polished) side of this travertine slab, and clearly reveals many diffractors or targets within the stone, that are visible upon inspection of the back side. When a selected pore was dampened, the moisture made a very strong diffractor on the radar image (lower right). Each image is 40 by 25 cm.

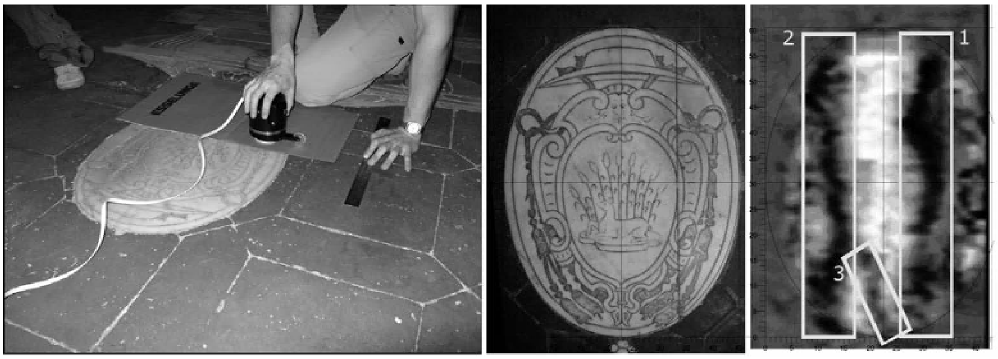


Figure 4. Process of medallion scanning using RASCAN (left). Metric comparison of optical image (center) with an holographic radar image (right). Three distinct contrast patterns are highlighted by yellow boxes.

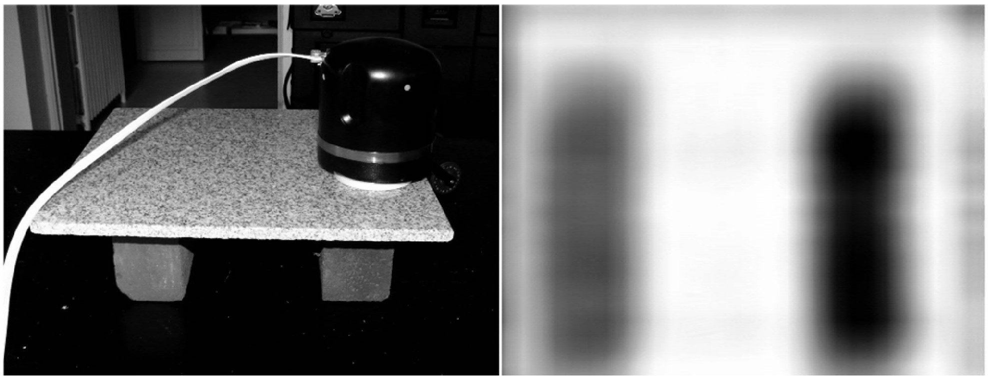


Figure 5. Laboratory model of the brick supports of the marble slab (left), and the 25 by 35 cm RASCAN image (right).

4 REFERENCES

Razevig, V. V., Ivashov, S. I., Sheyko, A. P., Vasilyev, I. A., Zhuravlev, A. V. 2008. An Example of Holographic Radar Using at Restoration Works of Historical Building, *Progress in Electromagnetics Research Letters*, 1: 173–179.

Ivashov, S. I., Razevig, V. V., Sheyko, A. P., Vasilyev, I. A., Zhuravlev, A. V., Bechtel, T. 2008. Holographic Subsurface Radar Technique and its Applications, *Proceedings of the 12th International Conference on Ground-Penetrating Radar, GPR 2008*.

5 ACKNOWLEDGMENTS

The authors wish to acknowledge the funding of NATO Project CBP.NR.NRCLG.982520.

5

Integration of space/air borne and ground remote sensing techniques for archaeology and cultural heritage

World Heritage Sites in South Asia: Enhancing geophysical surveys with satellite imagery

A. Schmidt[1], R. Coningham[2]

1 Archaeological Sciences, University of Bradford, Bradford BD7 1DP, United Kingdom. A.Schmidt@Bradford.ac.uk

2 Department of Archaeology, Durham University, United Kingdom, R.A.E.Coningham@Durham.ac.uk

Keywords: South Asia, geophysical survey, satellite imagery, World Heritage Sites

ABSTRACT

'Archaeological Remote Sensing', in its broadest sense, is at its best when all available information is jointly interpreted. This paper demonstrates how archaeological background understanding, satellite-derived context information and detailed analysis of geophysical anomalies are combined to investigate archaeological World Heritage Sites in South Asia. It is well known that simply listing all anomalies of a geophysical survey does not lead to the understanding of a site - data have to be interpreted archaeologically. This in turn requires a thorough understanding of the geophysical signatures associated with archaeological features in different geological and environmental settings. Satellite imagery (including derived topography) can provide a landscape context that allows appropriate archaeological hypotheses to be formed.

Site conditions were often difficult (e.g. dry soil, high vegetation, agricultural crops) and compromises in survey layout had to be made. However, combining results from confined areas into a data patchwork, using GIS, and complementing them with satellite data, resulted in meaningful site assessment.

1 INTRODUCTION

The purpose of archaeological prospection is to collect data that can be used for the non-destructive investigation of buried archaeological remains. The choice of method and methodology depends on the specific archaeological questions that need to be addressed. To analyse site location patterns, a broad landscape overview may be required which can be often be achieved with satellite imagery. For a more site-focussed approach high-resolution aerial photographs, collected under specific environmental and lighting conditions, may be best suited to reveal the individual features that make up a site. The detailed mapping and shape-analysis of these features is best undertaken with ground-based geophysical surveys. Only if the aim of an investigation is the analysis of soil conditions, the recording of construction and deposition microstratigraphy, or the recovery of eco and artefacts, invasive excavations may be required. To resolve the archaeological questions posed, results from all techniques have to be combined into a joint interpretation. This requires understanding of the technical details as well as the archaeological background. Simply listing all measured anomalies ("high magnetic bipolar anomaly", "circular cropmark") is not enough and a collaborative approach often achieves the best results.

There is no simple recipe for the interpretation of archaeological prospection data and it is hence useful to develop regional portfolios. As a framework, they help to identify the range of possible anomalies, potential archaeological features and a chronology of shapes and sizes. They can also be useful when selecting the best suitable techniques for a given task.

In South Asia, only few projects of geophysical archaeological prospection have been undertaken so far and the relationship between buried archaeological remains and measured geophysical anomalies has not been thoroughly explored. The authors therefore initiated a project to develop a regional portfolio for the use of archaeological geophysical techniques in South Asia, investigating sites in Bangladesh, Nepal, Pakistan and Sri Lanka. Satellite data were used to complement and contextualise geophysical data and an overview of this framework is presented here.

2 A SOUTH ASIAN PORTFOLIO

Most investigations that form parts of this study are related to World Heritage Sites in South Asia. In Nepal, Buddha's birthplace, Lumbini, and the associated sites of Tilaurakot and Ramagrama form a serial nomination located in the southern Terai. Occupation was identified at least from the 8th century BC. In Bangladesh, the Buddhist vihara (i.e. monastery) of Paharpur dates to the 8th century AD, while the extended complex of buildings at Bagerhat was founded by Khan Jahan in the early 15th cent. AD. From the 4th cent. BC to the 11th cent. AD Anuradhapura was the capital of Sri Lanka and had an important influence on the villages in its hinterland (Coningham *et al.,* 2007). Charsadda in Pakistan's North West Frontier Province is an impressive tell mound dating to the 6th cent. BC (Schmidt & Edwards, 2007). Based on investigations of these and other sites in South Asia several categories of characteristic parameters were identified.

2.1 *Archaeological Features*

A **campsite** was identified through excavation in Sri Lanka, after a surface scatter of pottery was discovered. The excavation identified several very shallow and ephemeral postholes, which were not recognisable in the magnetometer survey.

Vernacular buildings are probably the most common settlement features, but they are often constructed from perishable organic material or poor quality bricks. They hence leave only few traces in the archaeological record. To study their geophysical response, a magnetometer survey was undertaken at Wellaragam, Sri Lanka, a small settlement that had been abandoned in the 1950s. There were only vague surface impressions of the probable housing platforms but the magnetometer results delineated the area very clearly as high surface noise, probably due to the limited spread of waste and rubbish material within a confined area.

Secular palaces, although usually substantial and mostly built with brick walls, were often destroyed by subsequent rulers. If not bricks were reused in domestic buildings of subsequent settlers. Therefore, only fragments of foundation walls remain in the ground and the spread of brick rubble leads to blurred anomalies in the magnetometer surveys. Earth resistance data are less affected and the palace at Tilaurakot (possibly Kapilavastu) clearly shows the outline of structures similar to excavated areas nearby.

Religious buildings in contrast often survive fairly well as they are being looked after and respected by local communities.

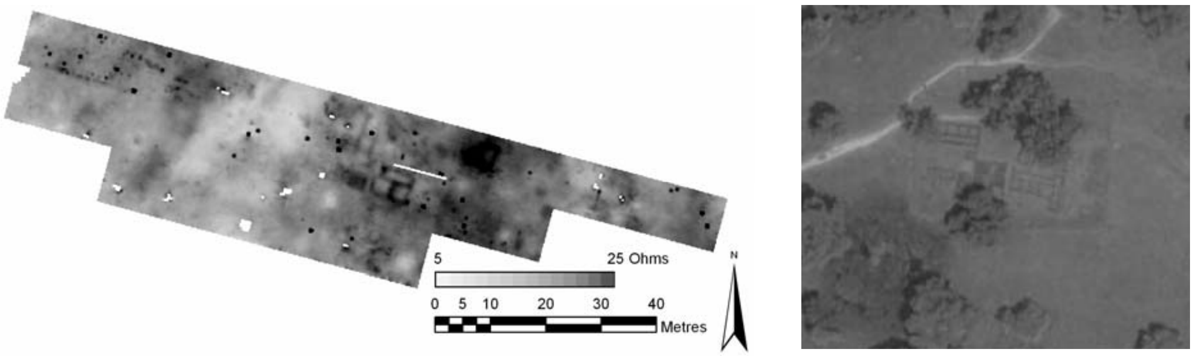


Figure 1. Tilaurakot, Nepal. Earth resistance data of palace. Satellite image shows similar structures on the same site (courtesy Google Earth).

2.2 *Building Materials*

Although **bricks** of abandoned buildings were often removed by locals as cheap building material, brick foundations sometimes remain in the ground and show a very clear magnetic contrast against the less magnetic sedimentary fill. At Ramagrama, Nepal, buildings with cellular structures were detected around a prominent mound and interpreted as small Buddhist monasteries (viharas) due to their shape and arrangement. These findings confirmed the religious importance already associated in antiquity with the site. On other sites, where brick rubble was spread after demolition, it is often difficult to detect features in the resulting randomised magnetic site matrix. On some sites earth resistance surveys can resolve these features better (see above).

Stones from **igneous geological** sources can produce distinct magnetic bipolar anomalies. If such stones were used as building material, magnetometer surveys help to distinguish between these buildings and the geological background. However, in some instances the magnetic anomalies of igneous geological features, even at several metres depth, are overwhelmingly strong so that small and weak anthropogenic anomalies cannot be resolved.

2.3 *Shape of Anomalies*

The shape of magnetic anomalies strongly depends on the latitude of the investigated area. In Sri Lanka, which lies on the 'magnetic equator' magnetometer data appear very different depending on whether they were collected with total field instruments (e.g. Caesium) or vertical component devices (e.g. fluxgate). To interpret such anomalies correctly the magnetic latitude (inclination) and the exact instrument type need to be known.

2.4 *Geology*

Broad geological trends often mask small changes that are caused by shallow archaeological features. In some instances filtering (especially high-pass filtering) can reduce the effect of such broad variations but sometimes even geological anomalies change with short wavelengths and are hence difficult to distinguish from archaeological features. It was found that magnetic anomalies caused by igneous outcrops in Sri Lanka often masked archaeological signals, thereby limiting the areas in which magnetometer surveys could be successfully applied.

Figure 2 shows earth resistance data form the Buddhist vihara of Paharpur, Bangladesh, before and after high-pass filtering. Filtering has enhanced some weak Y-shaped high resistance anomalies (running EW, then broadening to the east), which are interpreted as the foundations of earlier processional structures. Overlying onto the satellite image of the site (figure 3) the anomalies are neither aligned with the major temple in the east, nor with the gateway in the west, suggesting an even earlier construction than the upstanding monument.

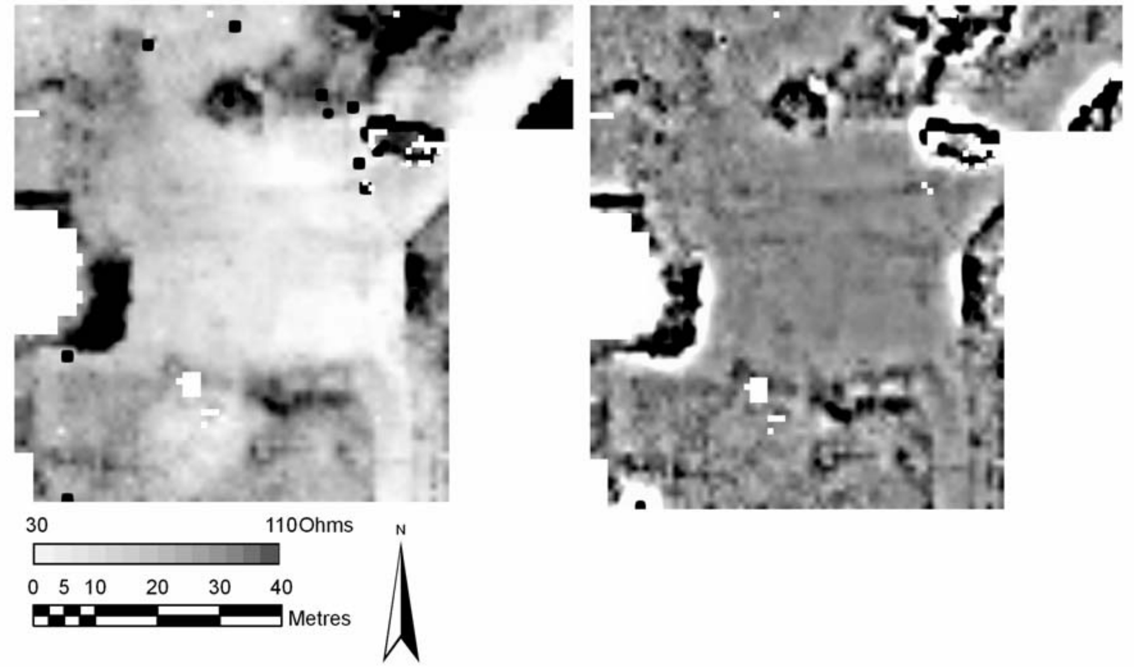


Figure 2: Paharpur, Bangladesh, earth resistance data before and after high-pass filtering

2.5 *Contrast*

It is often not known *a priori* in geophysical parameter show a contrast. Using electrical and magnetic methods together has therefore proved to be the best approach for maximising the information that can be gained from a site. It has become apparent that earth resistance data are often preferable since they usually show shapes more clearly delineated, improving the accuracy of archaeological interpretations.

Especially for features with weak geophysical contrast it is crucial that measurements are made with a high spatial resolution so that 'crisp' data plots are obtained (i.e. containing short-wavelength information). This makes it considerably easier to distinguish between archaeological features and unrelated variations in the soil ('soil noise', see Aspinall *et al.,* 2008). It was found that survey line spacings of 0.5 m are mostly sufficient. For earth resistance data station intervals of 0.5 m were chosen and magnetometer surveys were undertaken with 0.25 m sampling intervals.

The detectability of features is also strongly influenced by their burial depth. For magnetometer surveys the magnetic variability of covering sediments and soil often obliterates the weak signal created by archaeological features buried deeper than ca. 1 m. In earth resistance surveys the penetration depth is inversely linked to spatial resolution so that small features can only be identified if they are at shallow depth.

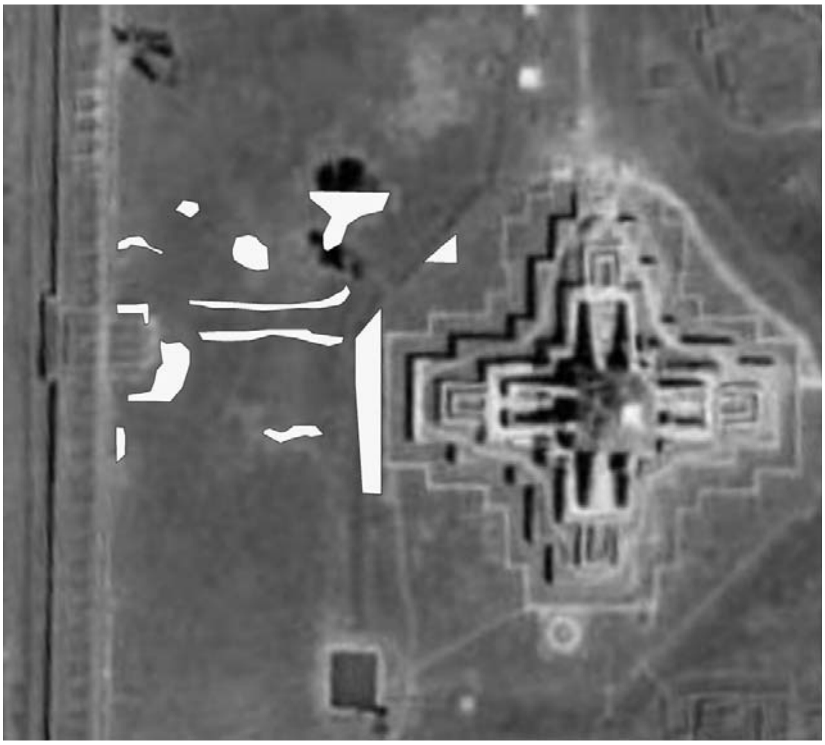


Figure 3: Paharpur, Bangladesh, interpreted earth resistance anomalies on different alignment. Image courtesy Google Earth

3 CONCLUSIONS

Archaeological and geophysical understanding is necessary to obtain meaningful and relevant interpretation of archaeological prospection data. The compilation of a regional portfolio allows to identify categories of characteristic parameters that facilitate such archaeological insight. Although satellite data were in this study not used to identify archaeological features on a site, they proved to very useful for providing the context in which the geophysical data could be interpreted.

4 REFERENCE

Aspinall, A., Gaffney, C., Schmidt, A. 2008. *Magnetometry for Archaeologists*. Lanham: AltaMira Press.

Coningham, R., Gunawardhana, P., Manuel, M., Adikari, G., Katugampola, M., Young, R., Schmidt, A., Krishnan, K., Simpson, I., McDonnell, G., Batt, C. 2007. The state of theocracy: defining an early medieval hinterland in Sri Lanka. *Antiquity* 81(313): 699-719.

Schmidt, A., Edwards, B. 2007. Surface Surveys. In R. A. E. Coningham and I. Ali (eds) *Charsadda: the British-Pakistani Excavations at the Bala Hisar* Society for South Asian Studies (British Academy) Monograph 5 BAR International Series. Oxford: Archaeopress.

Ground-based, aerial and satellite remote sensing to investigate archaeological and palaeoenvironmental features: the study case of Tavoliere (Apulia, Italy)

M. Ciminale[1], D. Gallo[1], R. Lasaponara[2], N. Masini[3]

1 Department of Geology and Geophysics, University of Bari, Campus, 70125 Bari, Italy; E-mail: marci@geo.uniba.it , d.gallo@geo.uniba.it
2 CNR, Institute of Environmental Analysis, C.da S. Loja, 85050 Tito Scalo, Italy; E-mail: lasaponara@imaa.cnr.it
3 CNR, Institute of Archaeological and Architectural Heritage, C.da S. Loja, 85050 Tito Scalo,Italy. E-*mail: n.masini@ibam.cnr.it*

Keywords: magnetic survey, aerial photographs, satellite, archaeology, palaeoenvironment,

ABSTRACT.

This paper is focused on the jointly use of multi-sensors, and multi-scale remote sensing technologies for supporting archaeological prospection. Aerial photos, satellite imagery, and high resolution magnetic surveys were adopted for studying Tavoliere, a very wide agricultural area in Southern Italy, characterized by an extraordinary presence of archaeological sites. A first recognition of the archaeological features was performed by historical aerial photographs; whereas satellite QuickBird and SPOT 5 images were used to obtain an up-to-date synoptic view of the study area. Archaeological features extracted from both aerial and satellite images, were further investigated by high resolution magnetic survey which provided a detailed reconstruction of buried remains. Results from our analyses pointed out that the integrated use of different remote sensing technologies can provide a significant contribution for the preservation, monitoring and management of the cultural resources, from a single site to a landscape perspective.

1 INTRODUCTION

Since the early decades of the last century and particularly after WWII, archaeologists have been studying the Tavoliere plain (Southern Italy), characterized by an extraordinary presence of archaeological resources (Bradford, 1949; Volpe, 2002; Romano & Recchia, 2006; Radcliffe, 2006). Nowadays, the ancient settlements have been only partially identified and reconstructed, even though the strategic importance of the region in the past times has been well documented and many information about different historical phases are now available. Due to the large extension of Tavoliere and the conspicuous number of historical settlements, archaeological research only based on the use of traditional methods (fieldwalking, trials, excavations and historical sources) is particularly difficult to be carried out. In such a context, the combined use of different remote sensing techniques (satellite, aerial, geophysics) could represent a very effective tool for extensively mapping and reconstructing ancient settlements (Ciminale *et al*., 2007) and palaeoenvironmental context. This multi-disciplinary, multiscale and multisource approach, besides its important scientific implications, can yield a relevant contribution in the protection of historical, archaeological landscape and cultural resources management. Such approach has been experienced for a test area, of about 18 sq km extension, located in the western part of Tavoliere (figure 1).

2 DATA ANALYSIS

2.1 *Aerial images*

A first recognition of the archaeological features was performed by using aerial data. Both oblique and orthophotos were specifically acquired for the project and analyzed along with supplementary images searched from old collections (Bradford, 1949; Jones 1987). This allowed us to perform a significant multitemporal analysis which is particularly useful and strongly recommended for the study area, involved in intense agricultural activities and modern landscape transformation.

Oblique photos were taken during the spring season in order to have sharp and evident crop marks which allowed the recognition of different types of anthropogenic structures and geomorphological traces. All the available oblique photos related to these sites were geocoded and mosaicked (Figure 1) with the purpose of increasing the informative content of the orthophotos. The orthophotos in scale 1:10000 show a diffuse and almost continuous presence of numerous ancient settlements. In particular, several Neolithic villages were clearly recognized. Three of them, Palmori, Schifata, and Salerno (see A, B and C in figure 1), are focused in this paper. These sites are relatively close each other (the maximum distance is less then 2400 m). Palmori and Schifata show a comparable extent (about 45 hectares) while Salerno site is much smaller (about 6.5

hectares). All of the three Neolithic sites are characterized by the presence of two or more external ditches circumscribing areas marked by traces of several internal compounds.

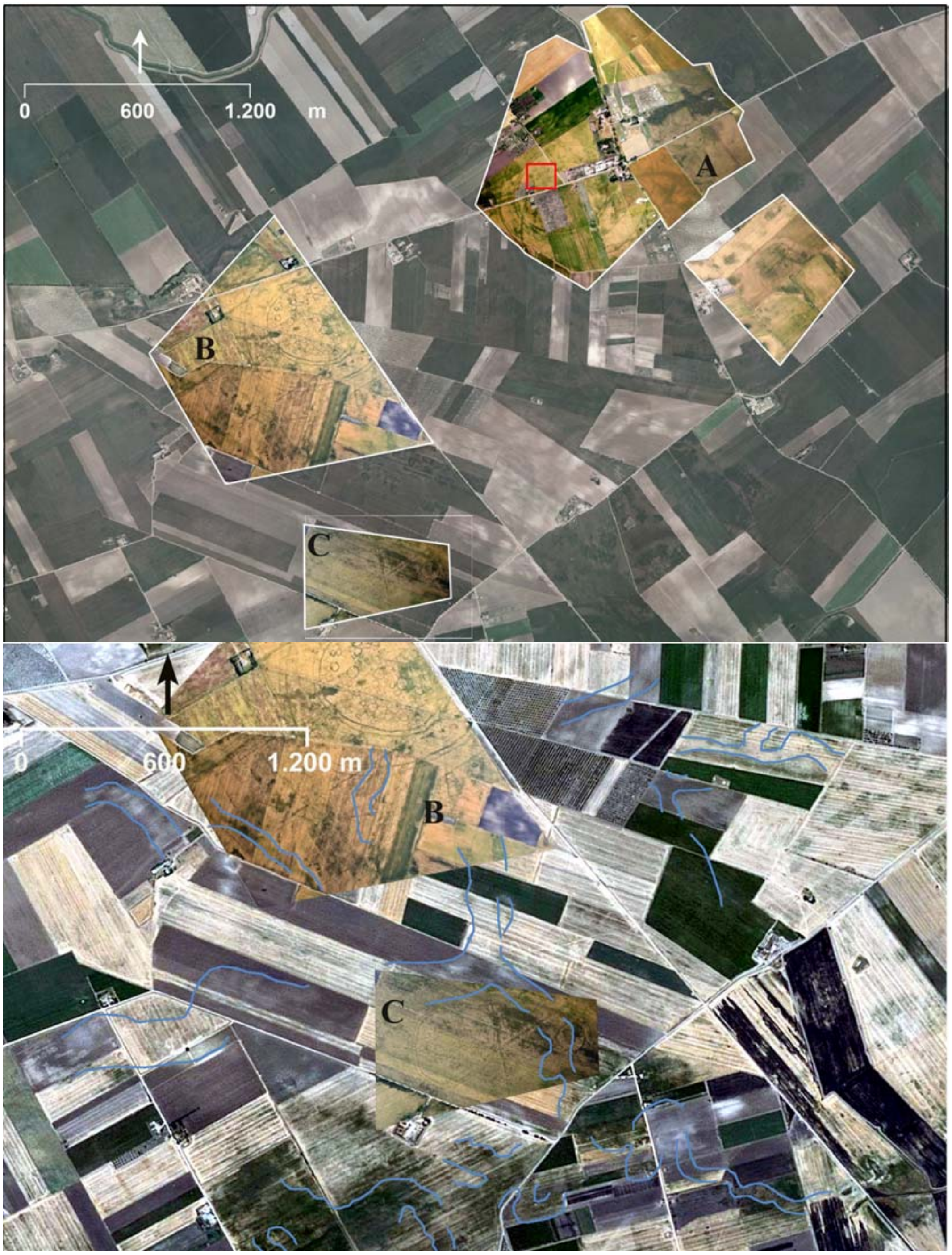


Figure 1. (top) Orthophoto of the test area. The white line delimits zones (285 hectares) where oblique photos were acquired and orthorectified. The letters A, B and C, indicate the 3 sites investigated that are respectively Palmori, Schifata and Salerno. The red box indicates the area zoomed (see figure 2) to show the results of classification. (bottom) Light blue lines show the palaeochannels identified from Spot in the surrounding of the neolithic sites of Schifata (B) and Salerno (C).

2.2 *Satellite images*

In this study satellite Quickbird (QB) and SPOT5 images were used. The analysis of satellite images were mainly addressed (i) to investigate palaeoenvironmental context and (ii) to extract cultural features by automatic unsupervised classification techniques.

The QuickBird is the commercial satellite that provides the highest spatial resolution of multispectral images. It has panchromatic and multispectral sensors with resolutions of 61-72cm and 2.44-2.88m, respectively, depending on the off-nadir viewing angle (0-25 degrees). The panchromatic sensor collects information at the visible and near infrared wavelengths and has a bandwidth of 450 – 900 nm. The multispectral sensor acquires data in four spectral bands from blue to near infrared (NIR) (see http://www.digitalglobe.com/product/product_docs.shtml). For this study QB images acquired on 2 July 2006 and 21 November 2007 were used.

The SPOT5 data are available at four spatial resolution levels from 20 m to 2,5 m (see http://www.satimagingcorp.com/satellite-sensors/SPOT-5_Resolution_Spectral_Modes.pdf) acquired in different spectral bands (B1: 0,50 - 0,59 µm; B2: 0,61 - 0,68 µm; B3: 0,79 - 0,89 µm; SWIR: 1,58 - 1,75 µm).

Both satellite QB and SPOT5 images were processed by using enhancement filtering. Among the many methods for contrast enhancement, for this study we applied the histogram equalization and Gauss method that are widely used and available in common image processing software. The histogram equalization improves contrast on the images by making the histogram more uniform. It redistributes the intensity distributions using a statistical process that has proven to be very effective. The Gaussian high-pass filtering increases the visibility of the high frequency information, in such a way special features are enhanced and easier detected by automatic processing or a human observer. QB and SPOT5 images were firstly filtered for enhancing edge and details and further analysed by (i) visual inspection and (ii) automatic classification techniques.

(i) visual inspection

Exploiting the synoptic view offered by satellite imagery we identified and tracked palaeo-channels. Herein palaeo-channels denote former river channels and/or stream courses along which during the rainy season water flowed for a short distance making the internal drainage. Figure 1-bottom shows the palaeo-channels in the surrounding of the neolithic sites of Schifata and Salerno. The identification of palaeochannel systems contributes to improve the understanding of the landscape evolution. The landscape perspective offered by satellite imagery can be successfully used to delineate the spatio-temporal relationships between paleoenvironmental conditions and the human settlements during past ages.

Aerial photos and satellite images were compared in order to verify potential archaeological features that can be easily distinguished in both the two datasets. The visual comparison put in evidence that a high percentage of archaeological features previously detecting by aerial photos (see section 2.1) are also evident in satellite imagery, despite their different spatial resolution and acquisition time. This fact confirms the spectral capability of satellite data already tested for other sites in Southern Italy (Lasaponara & Masini, 2007) by using QB multispectral images acquired in different periods of the year for several types of vegetation cover (crop or sparsely spontaneous herbaceous cover). The aerial photos were acquired in spring, during the green-up period for vegetation, considered the best period for crop mark identification for Mediterranean climate and environment. Whereas, satellite images were acquired in different periods of the year, including summer and autumn seasons that are considered not ideal for crop marks detection. As an example, figures 2 a and b show a zoom of the orthorectified aerial and QB image for a test area selected within Palmori sites (see red box in figure 1). Figures 2 c and d show the results obtained using Gauss and equalization enhancement techniques.

(ii) Digital image classifications

Digital image classifications allow us to identify and group pixels according to their similar scattering (within a single image) or spectral characteristic (within multiple images). Classification procedures can be differentiated into (i) unsupervised (automatic data processing) and (ii) supervised (semi-automatic data processing). The unsupervised classification techniques are performed without any prior knowledge of the image. Pixels are grouped into a pre-defined number of classes, according to their reflectance features. Supervised classification is a semi-automatic technique where the training phase is the basic step, to identify the spectral characteristics and group pixels according to the spectral signatures of the training areas.

In this work, unsupervised techniques were applied since the types (crop, soil or shadow marks) and spectral characteristics of archaeological features are assumed to be not known a priori. Unsupervised classification algorithms, such as K-means and ISODATA, are commonly used in remote sensing. Both of these algorithms were used for this study. The classifications were applied to the full scene and a subset selected as test-area (see red box in figure 1, up)

Results from K-means and ISODATA were quite similar. As an example, figure 2 shows details of results from ISODATA classification for the whole scene (e) and (f) Palmori subset. The typical circular and semicircular shape of the compounds of the neolithic sites are easily recognizable in both the figures. The red class of figure (e) is quite similar to the blue class of figure (f). The most important implication of this promising result is the possibility of searching for archaeological feature using an automatic processing tool. In such a way it should be possible to significantly reduce the amount of time and costs needed for fieldwalking and ground detection. Vast geographical areas may be investigated using multispectral imagery to extract potential archaeological and palaeoenvironmental features.

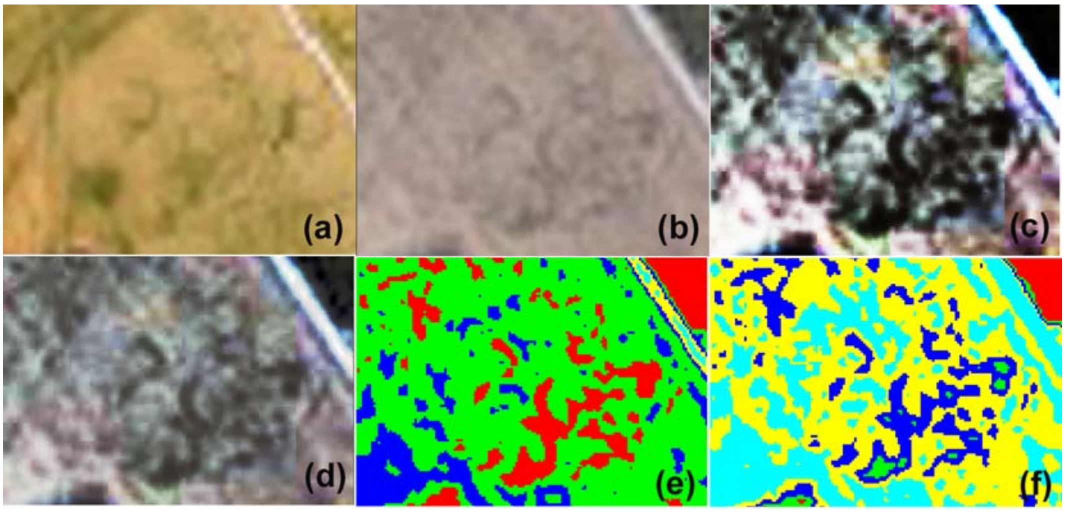


Figure 2. Zoom of a test area selected in Palmori site: (a) orthorectified aerial image (b) Quickbird image, (c) satellite image enhanced by applying Gaussian (c) and equalization method (d). Results from ISODATA performed on the full scene (e) and on a subset (f) for the same area as in figure 2a,b,c,d .

2.3 *Magnetic Survey*

Up to now, a high-resolution magnetic survey has been carried out only in a part of the study area; by adopting specific field procedures, an area of about 22 hectares were surveyed in 7 days, acquiring total intensity field measurements with a mean spatial resolution of 0.5 m X 0.125 m. Results from magnetic survey were integrated into a GIS in order to achieve a proper fusion of the obtained information. Data processing (Ciminale & Loddo, 2001) allowed to restore shape and values of the detected anomalies that in the final magnetogram describe with high detail the archaeological features. The acquisition grids were accurately geocoded through GPS differential measurements.

.

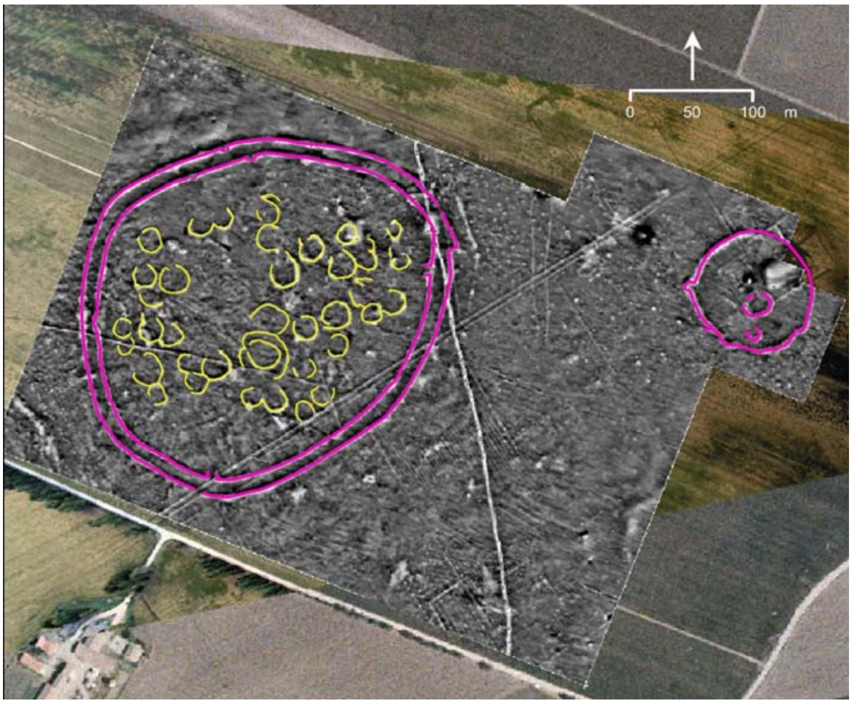


Figure 3 - Processed magnetogram obtained for Salerno site, overlapped to satellite and aerial data. All the archaeological features related to the Neolithic settlements are outlined with purple (ditches) and yellow (compounds) lines.

As concerns Salerno site, the additional information resulting from the magnetic data, allowed a more detailed reconstruction of the Neolithic settlement. The magnetic anomalies, outlined with colored lines, were sharper and more evident compared with the crop marks; thus defining the full map of the village (figure 3).

Quantitative evaluations were performed in the GIS environment. Some of them are here proposed; the settlement includes 38 recognized semicircular compounds surrounded by two external ditches with an average gap of 13 m. The plan of the village has a roughly elliptic shape and the magnetic anomalies clearly pointed out 6 entrances not visible in the aerial data. The layout of a smaller single-ditched enclosure, located approximately 200 m east of the main site, is also sketched in figure 3.

3 FINAL REMARKS

In this paper we experienced a multidisciplinary approach based on the jointly use of multi – sensors, and multi-scale remote sensing techniques for supporting archaeological prospection. Test sites were selected in Tavoliere (Apulia Region in Southern Italy) a huge agricultural area that is very rich in archaeological resources of different types and periods.

Aerial photographs, satellite imagery, and high resolution magnetic surveys were adopted for extensively mapping and reconstructing the ancient settlements. The multi-scale study has provided information useful for identifying (and potentially excavating) even very small structures and for supporting palaeoenvironmental study.

The database created for the test sites focused on this paper, was designed as a modular and scalable tool that is open to be continuously enriched with new available data, useful for improving the knowledge of the pilot sites or increasing the number of the study sites. The results we obtained for the Tavoliere pointed out that the combined use of not invasive techniques can have an important strategic role in planning sustainable policy of the territory, with particular reference to the monitoring and management of cultural resources.

4 REFERENCES

Bradford, J.S.P. 1949. Buried landscapes in Southern Italy. *Antiquity* 23 : 58-72.

Ciminale, M., Loddo, M. 2001. Aspects of magnetic data processing. *Archaeological Prospection,* 8 : 239-246.

Ciminale, M., Becker, H., Gallo, D. 2007. Integrated Technologies for Archaeological Investigation; the Celone Valley Project. *Archaeological Prospection,* 14: 167-181.

Jones, G.D.B. 1987. Apulia – Vol. I: *Neolithic Settlements in the Tavoliere*. Thames and Hudson Ltd, London.

Lasaponara, R., Masini, N. 2007. Detection of archaeological crop marks by using satellite QuickBird, *Journal of Archaeological Science,* 34: 214-221.

Radcliffe, F. 2006. *Paesaggi sepolti in Daunia - John Bradford e la ricerca archeologica dal cielo 1945/1957*, Claudio Grenzi Editore, Foggia.

Romano, A.V., Recchia, G. 2006. L'età del Bronzo nel Tavoliere interno: nuovi dati della ricognizione nella valle del Celone in: Atti 26o Convegno sulla Preistoria - Protostoria e Storia della Daunia. Gravina A. ed., San Severo, pp 205-252.

Volpe, G. 2002. Gli insediamenti rurali dall’età romana all’età tardoantica in: *Il mondo dell’archeologia*, volume 1. Ist. Treccani ed., Rome, pp. 911-917.

5 ACKWLEDGEMENTS

This research was supported financially by Ministry of University and Research (PRIN 06) and University of Bari EF 07-08.

Integration of remote sensing, geophysical surveys and archaeological excavation for the study of a medieval mound (Tuscany-Italy)

S. Campana[1], M. Dabas[2], L. Marasco[1], S. Piro[3], D. Zamuner[3]

1-University of Siena, Italy. campana@unisi.it

2-University of Paris, France. dabas@ccr.jusseu.fr

3-ITABC-CNR, P.O. Box 10 00016 Monterotondo Sc. (Roma, Italy). Salvatore.piro@itabc.cnr.it

Keywords: Remote sensing; differential magnetic, GPR, ARP, medieval mound

ABSTRACT.
The studied area has been detected from the air in spring 2005. The evidence represents in early middle age a survival of the population pattern in the lowland, probably in deep relationship with peculiar resources (swamp, road systems, etc.). Analysis of the aerial photographs allowed already the interpretation of the site as a triple enclosure. During the first field walking survey, based on a grid of 10 by 10 m, archaeological artifacts were collected and localised. The DGPS survey confirmed the morphological pattern of the site. The field walking survey and DGPS measurements have been followed by an integrated geophysical surveys employing: differential magnetic (Overhouser probe), Ground Penetrating Radar (GSSI SIR 3000, equipped with 500 MHz antenna) and ARP (Automatic Resistivity Profiler, Geocarta patented system). At last, in the month of September 2007, three sample areas addressed mainly to verify the collected evidence, were excavated. The evidence of a timber castle (ditch, post-holes, domestic pottery, animal bones, wall with perishable materials) has been found. This evidence can be interpreted as the first medieval mound in Tuscany.

1 INTRODUCTION

The site investigated is close to the castle of Scarlino along the seaside on the west coast in the province of Grosseto. This landscape has been studied from the Department of Archaeology of the University of Siena since 1979, when the late professor Riccardo Francovich started the archaeological excavation of the castle of Scarlino (Francovich, 1985). Almost at the same time, in relationship with the excavation, followed a fieldwalking survey that contributed to make this landscape one of the more studied in the province of Grosseto (Cucini, 1985).

So, our site has been already pointed out in the past by air photo interpretation of vertical historical coverage. Unfortunately the absence of a mapping project of the features and the unavailability of GPS device for navigation made the identification of the evidences on the field more and more difficult. Despite the analysis of the aerial photo allowed already the interpretation of the site as an triple enclosure, the lack of a correct check on the ground avoid to understand the chronology of the site and also any contribution to the development of new settlement pattern. In this paper we present how the quality and the quantity of the information we achieved open new perspective for the archaeological research in the landscape around the site. The site whose place name is Castellina (showing a possible relationship with a castle) is set to the centre of a large coastal lowland posts behind the gulf of Follonica. This area has been characterized in the past from a wide brackish lake (figure1).

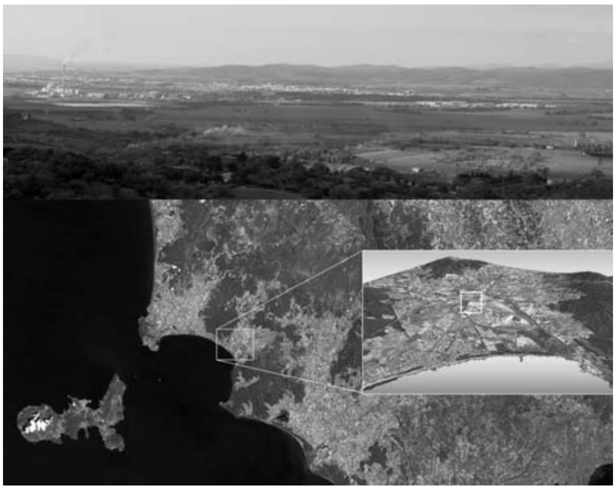


Figure 1 – Tuscan coast and the lowland of Scarlino

The attempts of reconstruction of the ancient lake boundary set our site in proximity of the ancient internal coastline (Bartolini *et al*, 1977). Although the archaeological case study is just at the beginning, at the first glance the site look to have be in deep relationship with the surrounding context and with the economical activities that here developed. Anyway the past researches allow to interpret the medieval landscapes focused in the hilltop village of Scarlino starting from the early medieval Age. Here, the archaeological excavation, above evidence that goes from the Bronze Age to the imperial Roman Age, has showed the rests of a village, turned into curtis in the IX century B.C. and transformation of the settlement into a castle starting from the end of X century (Francovich, 1985).

The case study we discuss in this paper represents in early middle age a survival of the population pattern in the lowland, probably in deep relationship with peculiar resources (swamp, road systems, etc.).

Starting from September 2005 the site was investigated by several different kind of archaeological survey: field walking survey (we collected artefacts in a grid of 10 by 10 m), DGPS survey to define the morphological pattern of the site, magnetic survey (Overhouser), ARP® survey (Automatic Resistivity Profiler, Geocarta), GPR survey (GSSI SIR 3000). After collecting a wide range of datawe opened , in September 2007, three test-excavation to verify the survival entity of archaeological startigraphy and the correspondence with geophysical features.

2 AERIAL SURVEY

In 2005 – during the XIV International School in Archaeology organized in collaboration with the Culture 2000 project, *European landscapes: past, present and future* – several flights with light aircrafts allow to acquire many oblique aerial photographs of distinguished archaeological cropmark. The features consists in a triple concentric circular enclosure with a fourth trace in the centre and a fifth on the left side of the second enclosure. Moreover some parallel linear traces that overlap the enclosure were underlined. The circular enclosures – that surround an area of almost one hectare – could be basically related to ditches and/or palisade. The evidence inside and outside the smaller enclosure could be related generically to buildings (figure 2). The mapping process allow to better understand and overcome the problem we pointed out at the beginning of the paper related to the absence of evidences on the ground. Past aerial reconnaissance on the vertical aerial photographs (for instance the national coverage of 1954) was also successful. Nevertheless, the absence of systematic mapping project and the inaccuracy in site positioning (mainly because of the map scale 1:25.000) shifted of at least one hundred fifty meters northeast the representation on the map of the site.

3 GROUND SURVEY

On the ground is quite easy to recognize the correspondence between features and the mound that raises for around 1 m on the surrounding plan. We surveyed the area using a DGPS system to collect precise information on the morphology of the site. The result is a very detailed cloud point that we interpolated using the circular krieging algorithm and that we imported in the GIS to integrate the data interpretation. The DEM we obtained clearly confirmed the presence of a slight hill cut by some deep ploughing ditches.

Field walking survey has been done in September 2005, immediately after ploughing, in good light condition and with excellent archaeological visibility that allow us to see a relatively high quantity of pottery. On the ground we understand immediately the high archaeological and historical value of the site, also realizing that some of the pottery could be dating to the early medieval Age. Considered the weakness of the material culture of this chronological period we ought to be very careful and we organized a grid collection with square of 10 by 10 m. The study of pottery allow us to identify the first phase of the site starting from the VIIIth century D.C. and the end at the beginning of XIIth century B.C.

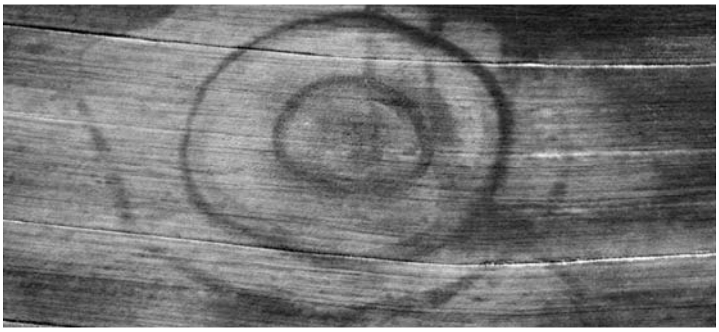


Fig.2 – Oblique aerial photographs of distinguished archaeological cropmark

3 MAGNETIC SURVEY

The magnetic survey has been done immediately after the fieldwalking survey and the artefact collection on a ploughed surface. This condition are not excellent because introduced quite a lot of noise in the data making the post processing more and more complicate. The measurements have a resolution of one meter between the profiles and between 30 to 50 cm along the line. The surveyed area is 2 hectares and correspond to the features visible on the oblique aerial photo and mainly to artefacts scatter.

The interpretation of the magnetic map allow to recognize - with a degree of detail quite similar to the oblique photography - several features. At least the map show three concentric enclosures and in the centre a rectangular feature that is probably possible to interpret as a building. Other features are mainly related to small dipoles that reach the higher density inside and immediately outside the smaller enclosure. These traces are very difficult to interpret mainly because of the low resolution of the survey. Considered the peculiarity of this typology of evidence, a medieval mound, an hypothesis - that find parallel with other case study - could be related with post holes. Anyway to better understand the site could be useful, in the next future, to repeat the magnetic survey increasing the resolution between profile up to 50 cm (Campana, Francovich, Marasco 2006).

4 GPR SURVEY

With the GPR method a high-resolution data acquisition technique has been adopted with the aim to reconstruct a global vision of the investigated volume of subsoil. GPR surveys were performed during July 2007, employing a SIR 3000 (GSSI) equipped with a 500 MHz bistatic antenna set to a constant transmitter - receiver offset. Single-fold exploratory profiles were first carried out at the site with the objectives of : i) preliminary identification of the targets; ii) calibration of the instrument; and iii) analysis of the subsurface response as a function of the orientation of the profiles. Some signal processing and representation techniques have been used for data elaboration and interpretation (Goodman *et al.*, 2004; Piro *et a.l,* 2003, 2007).

A total of 101 adjacent profiles at the site were collected alternately in reversed and un-reversed directions across the survey grids. The horizontal spacing between parallel profiles at the site was 0.5 m. Radar reflections along the transects were recorded continuously across the ground at 70 scan s^{-1}; horizontal stacking was set to 4 scans. Along each profile markers were spaced every 1 m to provide spatial reference. All radar reflections within the 70 ns (two-way-travel time) time window were recorded digitally in the field as 8 bit data and 512 samples per radar scans. Referred to as time slice processing, these anomaly maps can be generated at various time/depth windows across the recorded radargram dataset. The time slice maps can provide information regarding the size, shape, location and depth of subsurface archaeological structures buried beneath a site (Goodman *et al.*, 2004; Piro *et al..*, 2003, 2007; Gaffney *et al.*, 2004).

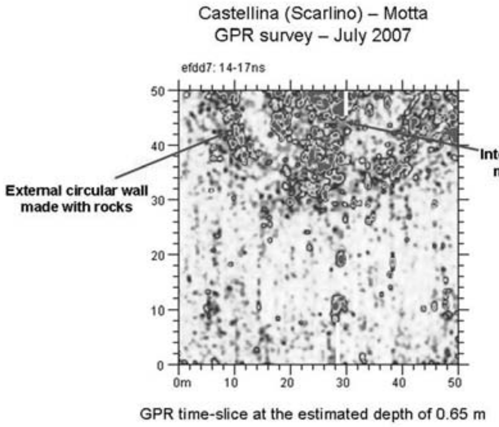

Castellina (Scarlino) – Motta
GPR survey – July 2007
efdd7: 14-17ns
50
40
30
20
10
0
0m
10
20
30
40
50
External circular wall made with rocks
Internal circular wall made with rocks
GPR time-slice at the estimated depth of 0.65 m

Fig. 3 - GPR time-slices at the estimated depth of 0.65 m in the area which covers half space of the site are shown.

Time slice data were created using the spatially averaged square wave amplitudes of the return reflection. The squared amplitude, which is essentially the energy in the waveform, was averaged horizontally every 0.25 m along the radargram profile, and in 4 ns time windows to create a time slice parameter. These averaged square amplitudes were then gridded using a Kriging routine that included a search of all data within a 1.0 m radius of the desired point to be interpolated on the grid.

Some radargram filtering was used to remove the background reflections. Other line noises, parallel to the profile direction, were removed using a moving filter with customized threshold settings.

A high-to-low amplitude scale is normally presented as part of the legend of each map, but without specific units because, in GPR, absolute reflected wave amplitudes are usually arbitrary. For the elaboration and representation of GPR data, the GPR-Slice software (by D. Goodman) has been employed.

In figure 3 the GPR time-slices at the estimated depth of 0.65 m in the area which covers half space of the site are shown. The analysis of these slices shows that this zone is characterized by the presence of clear anomalies due to many small reflectors (rocks), forming a circular distribution as wall remains. This distribution presents a good matching with the gradiometric anomalies.

5 ARP SURVEY

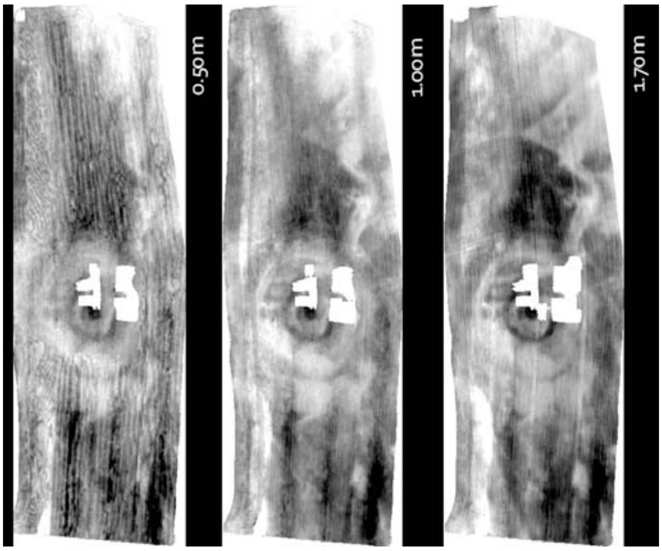


Fig.4 - *ARP maps at different depth and related sample area.*

In autumn 2007 the site has been surveyed employing the Automatic Resistivity Profiler (ARP©). This system has been developed in France by the GEOCARTA company, a CNRS France spin-off (Dabas 2008).

The principle of ARP© is rather simple, relying on the standard galvanic electrical method, used widely for different applications since its discovery by Marcel and Conrad Schlumberger in the 1930s. The ARP© system was first designed for agricultural applications in 2001. It was not until 2004, however, that the system was released for archaeological surveying, because of the need to enhance its positional and measurement accuracy. The surveyed area involves the whole of the site and its surroundings to a total extent of about 5 hectares.

All the raw data have been processed by a 1D median filter along transect first and then interpolated by a spline bicubic process on a squared mesh (40cm x 40cm for investigation depths 0-50cm & 0-100cm but 50cm x 50cm for the deeper one (0-170cm). In this occasion we show the maps of apparent electrical resistivity at different depths of investigation using a black & white colour scale (figure 4). The results of ARP are extremely interesting. The ARP© data makes it possible to add new information to the nothern side of the surveyed area but also to integrate information on known features. The survey also produced a high resolution DTM of the investigated area.

6 EXCAVATION

In September 2007 we did three test-excavation to verify the more significant geophysical features interpreted as trace of building in the centre of mound and one of the ditches.

In the area inside the more internal ditch was discovered a phase of pit holes (in one we found part of the burnt pole), identifiable maybe as last phase of the settlement, unfortunately damaged a lot by recent agricultural activities. Under this we found an interesting earlier layer with big stone, pottery and black hearth, potentially relatable to the collapse of some stone building: for this older archaeological phase is possible to hypothesize a much better conservation.

The second test-pit cut the smaller ditch and is aimed to localize and to define its real dimensions. We were able to identify external line of the ditch, filled with many layers of charcoal and burned stone. On the internal side of ditch was discovered a rest some stone structure, collapsed in part, but maybe built along circular line of ditch. Unfortunately, in this test we had not enough time to deepen archaeological investigation and to understand the relationship between the two elements.

Analysing the results of excavation we can consider a very good conservation level of the archaeological context and we are able to define at least two different large historical phases: we recovered in both some traces of building activity with huge use of wood, stone and clay, elements that we can connect to different kind of structures with perishable materials. This result find good correspondence with the hypothesis about the early medieval fortified settlements.

7 CONCLUSION

Both methods, aerial photographs and geophysical prospections, underline features that is possible to interpret as a timber proto-castle in the lowland characterized from at least three concentric defensive evidences.

But we should be careful on that. Aerial reconnaissance apply principles and study parameters completely different – for instance – from the magnetic data interpretation. Archaeologist are mainly used to interpret features in relationship with their shape and size. We may consider that there is a significant difference between the meaning of the two soil measurements, the first one related with colour property and the second with magnetic property. Starting from this perspective the comparison between the aerial photograph and the magnetic map don't show any redundancy. The magnetic measurement of the smaller enclosure record a very high continues signal that could probably means the presence of higher concentration of organic material, may be related to a palisade. The georadar data show the presence of a circular wall internal and external to this smaller enclosure as well as the ARP data present higher resistivity: test-excavation confirm the geophysical data discovering parts of a structure, built along the circular ditch.

The reconnaissance in the central part of the mound of a possible building in rectangular masonry it also finds besides correspondence with the magnetic map but also with the field walking survey. The results of the artefacts collection in that area showed the high density of stones and mortar. Also here, the excavation has revealed correspondence with the magnetic, electrical and GPR anomalies, recovering some evident traces of a large collapse of stone building. The available data allow us to interpret the site as an early medieval fortified settlement datable starting at least from the 9th century d.C. whose main peculiarity are the fortress typology and the related position in the lowland.

Finally, we want to emphasize that before applying an integrated approach like that we just show no mound where known in Tuscany. In the last five years we discovered four mounds placed between Grosseto and Piombino. This is even more peculiar if we consider that Tuscany is one of the main studied region of the whole Europe. This trend should be possibly related to the oddness of the traces that mounds leave on the ground. We mean "negative" traces, extremely difficult to detect through field walking survey but extremely visible in ideal condition from the air or detectable throughout geophysical prospection.

8 REFERENCES

Bartolini, C., Pranzino, E., Lupia Calmieri, E., Caputo C. 1977. Studi di geomorfologia costiera: IV – L'erosione del litorale di Follonica, *BS Geol.* I, 96 : 87-116.

Campana, S., Musson, C., Palmer, R. 2005. *In volo nel passato. Ricognizioni aeree e aerofotografia obliqua*, Firenze.

Campana, S., Francovich, R., Marasco, L. 2006. *Remote Sensing and Ground-Truthing of a Medieval Mound (Tuscany - Italy)*, From Space to Place, Cambridge.

Cucini C., 1985. *Topografia del territorio delle valli del Pecora e dell'Alma*, in Francovich R. 1985, 147-335.

Francovich, R. (ed.) 1985°. *Scarlino. I. Storia e territorio*, "Ricerche di Archeologia Altomedievale e Medievale", 9/10, Firenze.

Francovich, R., Hodges, R. 2003. *Villa to village. The transformation of the Roman Countryside in Italy, c.400-1000*, Duckworth, London.

Gaffney, V., Patterson, H., Piro, S., Goodman, D., Nishimura, Y. 2004. Multimethodological approach to study and characterize Forum Novum (Vescovio, Central Italy). *Archaeological Prospection*, Vol. 11, pp. 201-212.

Goodman, D., Piro, S., Nishimura, Y., Patterson, H., Gaffney V. 2004. Discovery of a 1st century AD Roman amphitheatre and other structures at Forum Novum by GPR. *Journal of Environmental & Engineering Geophysics*, 9, 1: 35-41.

Marasco, L. 2006. Forthcoming, *Scarlino. Nascita e sviluppo di un castello medievale.* L'indagine archeologica, Firenze.

Piro, S., Goodman, D., Nishimura, Y. 2003. The study and characterization of Emperor Traiano's Villa (Altopiani di Arcinazzo, Roma) using high resolution integrated geophysical surveys. *Archaeological Prospection* 10: 1-25.

Piro, S., Peloso, D., Gabrielli, R., 2007. Integrated geophysical and topographical investigations in the territory of ancient Tarquinia (Viterbo, Central Italy). *Archaeological Prospection*, 14, 3 : 191-201.

Using of VHR satellite data for potential digs localisation and their verification using geophysical methods

K. Pavelka, M.Bukovinský, J.Svatušková

Laboratory of Photogrammetry, Dept. Mapping and Cartography, Czech Technical University in Prague, Prague 6,Thákurova 7, 166 29Czech Republic. Tel.:+420224354951, Fax:+420224310774, E-mail: pavelka@fsv.cvut.cz.

Keywords: VHR data, cultural heritage, satellite image, archaeology, geophysics

ABSTRACT

The Middle Europe region is inhabited by humans tens of thousands years. In the Czech Republic, there are a lot of findings, which are an evidence of this. Finding of potential long-past human activities is very useful and economical often by using aerial methods. From the seventies of 20th century, the geometrical resolution of satellite data has increased from 80m to 0.5m (160x!). Nowadays, we have a possibility to use a new type of VHR satellite data with a resolution less than 1m. In this case, the geometrical resolution is comparable with high altitude photogrammetry, but the spectral resolution is much better. Very important is the date and time of image acquisition and the season. Every terrain signature is visible differently and at another time. By adding of new spectral channels and using of IR photos we extend present possibilities of this method to a new level. Finding of methodology or acceptable spectral band combination and following pre-processing of a satellite image for the visualization of surface and underground archaeological information is the aim of this paper.

1 THE USING OF AERIAL PHOTOGRAPHS

At the Institute of Archaeology of the Academy of Sciences, aerial photographs have been traditionally used since nineties of last century. The Institute has from a large project small aircraft Cessna at disposal. Only oblique and non-metric images are used, made especially for archaeological use on time. A lot of archaeological findings were succeeded by this method. Some objects are visible only a few days in the year, some objects only by special vegetation and weather configuration, that are only from time to time (e.g. one times per 10 years).

2 NEW POSSIBILITIES IN ARCHAEOLOGICAL PROSPECTING

In the last ten years, new methods are implemented in archaeology. It means new sensitive geophysical methods and very high resolution remote sensing. In the case of remote sensing, new types of very high-resolution satellites (with sub meter resolution) are at disposal; the geometrical resolution is now similar with aerial images, but the radiometrical and spectral resolution is by satellite images much better. Of course, very important is the date and time of image acquisition and the season. Every terrain signature is visible differently and at another time. By adding new spectral channels and using of IR photos we extend present possibilities of this method to a new level.

2.1 *The project at the CTU Prague*

At the CTU in Prague, we have started new projects exploiting both of above-mentioned methods. In this frame, we collaborate with the Institute of Archaeology of the Academy of Sciences, which uses active aerial methods since 1994.

There are three special scenes from QuickBird satellite that were used at the Laboratory of remote sensing and photogrammetry for this project. They were acquired on: 24.09.2005 (Neratovice), 03.05.2006 (Podřipsko A), 23.04.2005 (Podřipsko B)

The archaeological findings are best visible in the Czech Republic by their vegetation indices. For this reason, the best time for data acquiring is mid of spring, in rapid vegetation process. Another option is the soil indices – the best time is early spring or autumn, after crop. A new progressive method is laser scanning, which can be used for spatial indices such as residual mounds, burial-mounds etc. Data processing is based mainly on visualization and manual classification. Image enhancements, filtering (edge sharpening) and spectral channel mixing are used. The NIR data channel is very important. In this process, the NDVI was used with better results on areas with vegetation, next the pan-sharpening function and red/blue channel ratio. The prospecting of potential findings is primarily focused on areas with a long-term settlement in agricultural areas. Some areas with potential findings were classified by using ISODATA and K-means unsupervised classifications, but the results were not very demonstrative; only in case of expressive indices were results useful. For the processing, the orthophoto mosaic of the Czech Republic was used at the same time (resolution 1m with access free internet application or 50-20cm by paid access). In the case of orthophoto mosaic, there are used many aerial photos in different time and season (of course not only in suitable time for aerial archaeological prospecting), but the orthophoto mosaic is a very good material for this work. All results are georeferenced by using GCP to the Czech national geodetic system; the output of potential findings to GPS coordinates (WGS 84) is possible by common transformation.

From 44 old known digs located on processed satellite images were only 7 verified, however there are located 8 non-known potential findings (!). That is why, the dimension of many digs is very small (or line width pattern), and the time or season was not good for successful verification. Other case, better spectral (NIR channel) and radiometric resolution give a possibility for localisation of new findings.

3 FINDINGS VERIFICATION

The visualized information is used to verify some known archaeological localities and also to look for new localities, which will be verified in the terrain afterwards. The work gives the following results: the graphical displaying of archaeological localities, the estimation of use image sharpening methods and the evaluation of possibility for using this research method in archaeology.

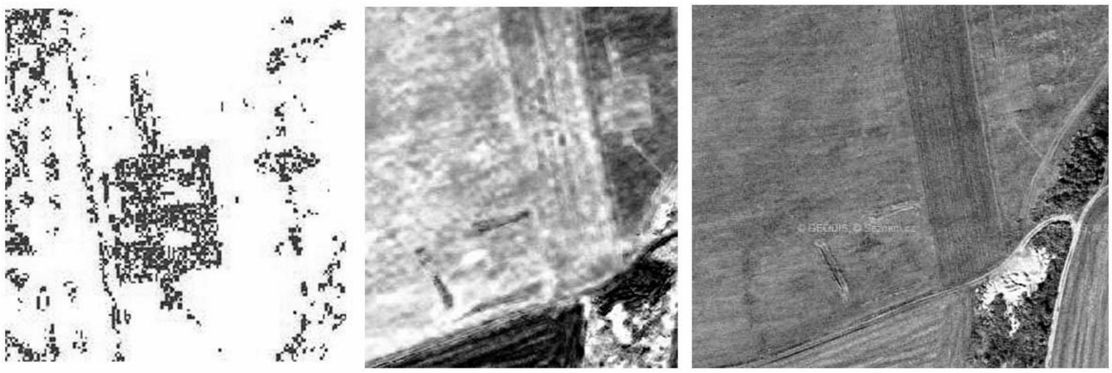


Figure 1: Object Neratovice X4 (left- satellite image classification, middle – QuickBird pan, right – orthophoto –2005, Geodis,a.s., www.mapy.cz)

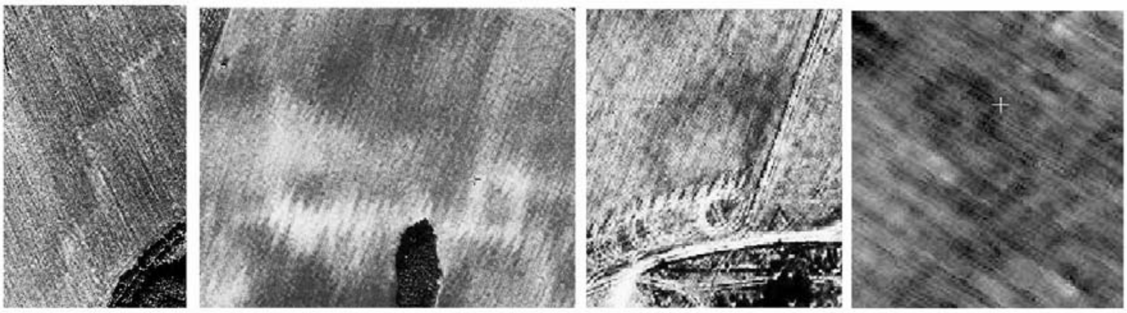


Figure 2: New potential findings from QuickBird image: Neratovice X6, X2, X1 and X5

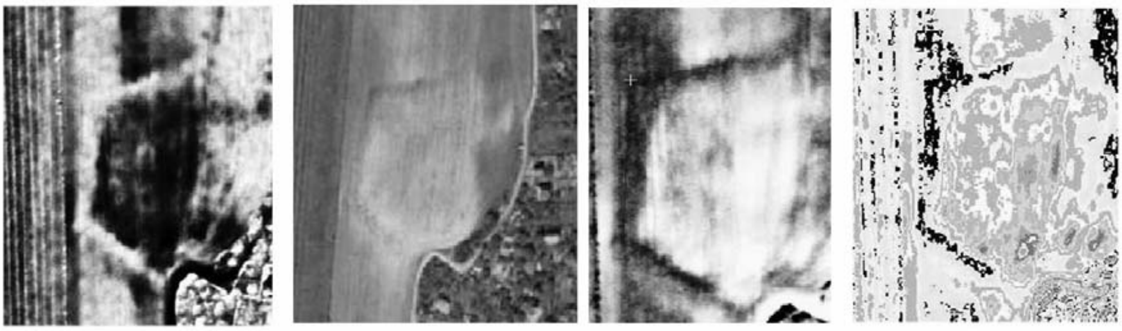


Figure3: Verified object PodripskoA – B3-B1 Pan-sharpened image (QuickBird) and enhance –eqv.,, orthophoto-mosaic and K-means unsupervised classification; a part of bigger structure on the next images (left on images)

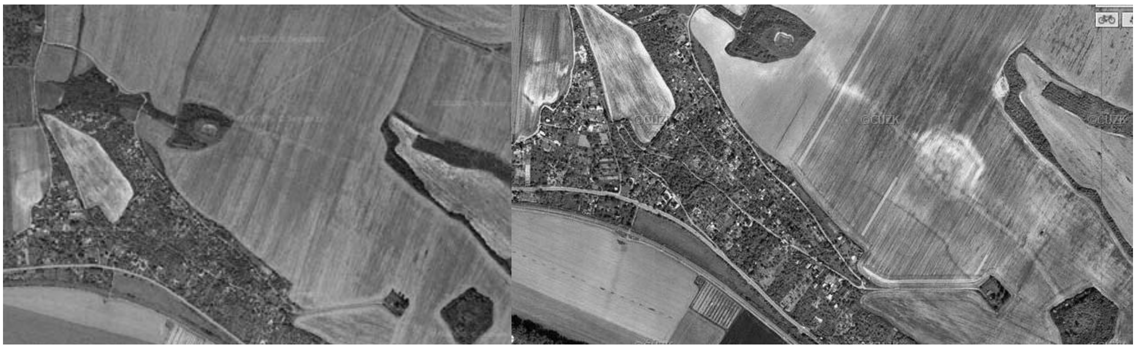


Figure 4: Orthophoto from 2005 (ČÚZK) and 2005 (Geodis,a.s.) – same area, different season (emplacements from Prussia – Austrian war?)

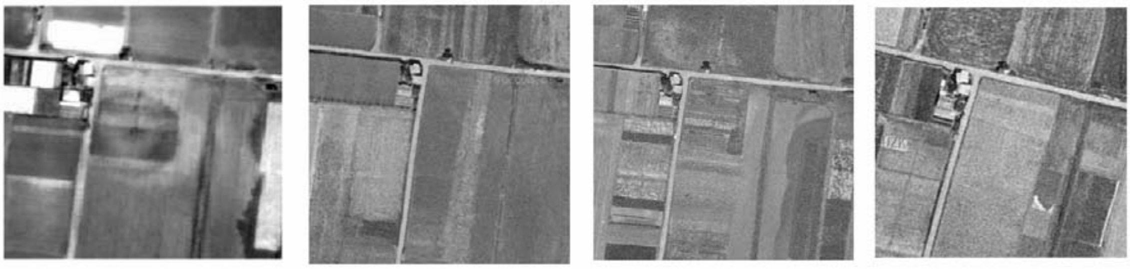


Figure 5: New object Podripsko X1 (Terezín)- potential finding in Central Bohemia (on the left – potential burial mound on satellite image from QuickBird, or a circular irrigation?) on the right – orthophoto 2003 and 2005 Geodis a.s., www.mapy.cz; orthophoto 2005, ČÚZK, www.amapy.cz)

The logical next step is a verification of these findings by using terrestrial methods – in this case by using geophysical instruments. At the CTU Prague, we extend terrestrial geodetic measurements to other dimension – to the underground. The gradiometer GSM-19 and georadar SIR-3000 are newly for use at the Faculty of Civil Engineering (however, the Institute of Archaeology of the Academy of Sciences uses the geophysical instruments since nineties of last century). After crop, we will work on verification of new potential findings.

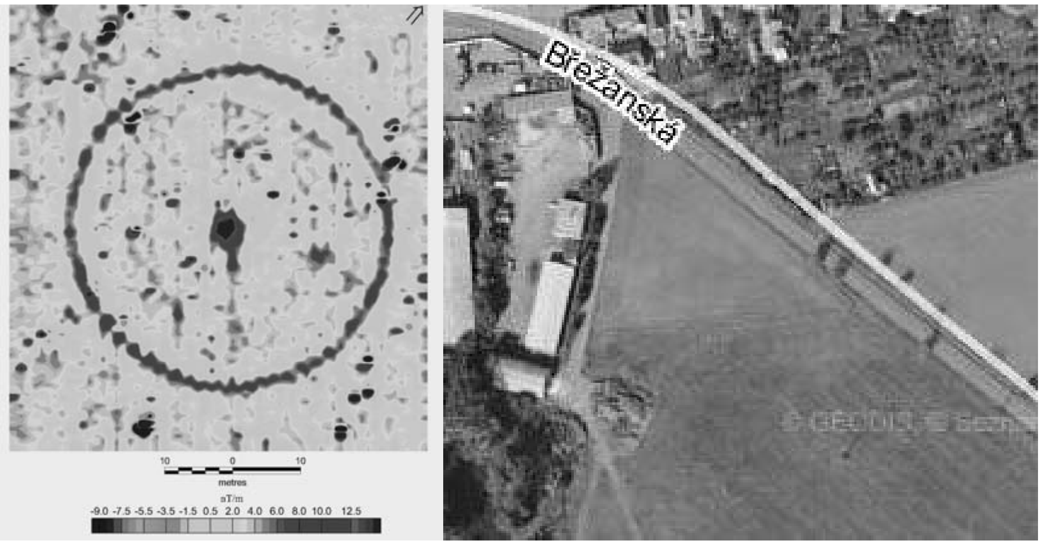


Figure 6: Geophysical verification of burial-mound in Dolinek Village (Křivánek, 2006) and orthophoto without digs indices (Geodis,a.s., www.mapy.cz)

3.1 *Geophysical prospecting*

The GSM-19 v7.0 Overhauser instrument is a total field magnetometer /gradiometer of choice in today's earth science environment, in this case in archaeology. Overhauser effect magnetometers are essentially proton precession devices - except that they produce an order-of magnitude greater sensitivity. First results of this instrument at the CTU in Prague in the field of archaeology and digs verification will be presented in this year.

This research has been supported by grant MSM 6840770040 (CTU 34-07401).

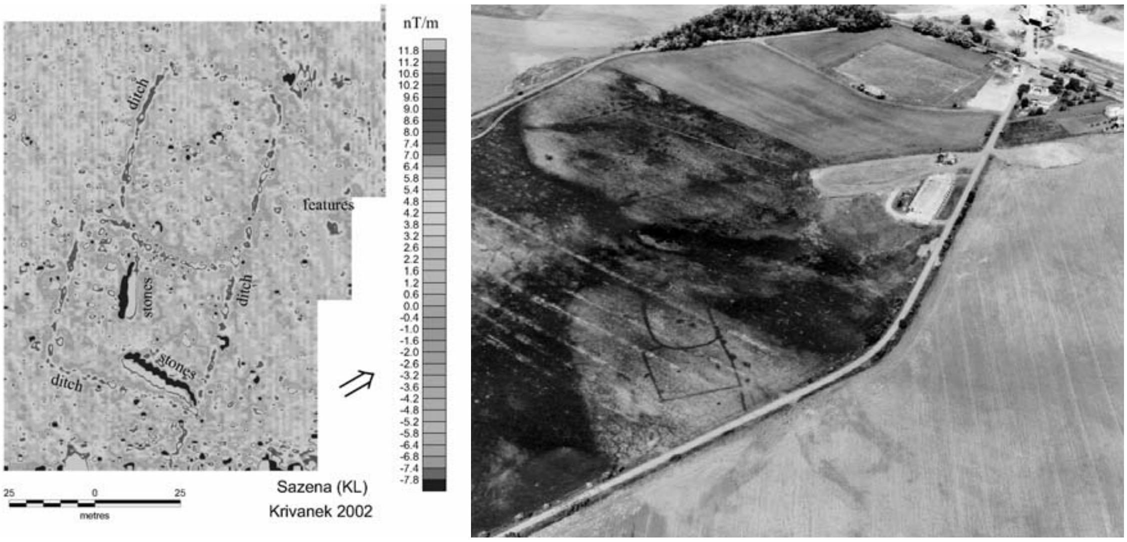


Figure 7: Geophysical verification of findings in Sazena Vilage (Křivánek,2002) and aerial image (Institute of Archaeology of the Academy of Sciences)

4 REFERENCES

Gojda, M. 2005. Features, Sites and Settlement Areas in the View of Air Survey (Bohemia, 1992-2003). In: *Air Photography and Archaeology 2003. A Century of Information* (J. Burgeois – M. Meganck eds.), 101-111. Gent.

Gojda, M. 2002. Aerial Archaeology in Bohemia at the turn of the twenty first century: integration of landscape studies and non-destructive archaeology. In: *Aerial archaeology. Developing future practice* (Bewley, B. – Raczkowski, W. eds.), 68-75. Amsterdam-Berlin-Oxford-Tokyo-Washington D.C: IOS Press.

Křivánek, R. 2004. Geophysical prospection. New perspectives for settlement studies in Bohemia. In: Gojda, M. (ed.) et al.: *Ancient Landscape, Settlement Dynamics and Non-Destructive Archeology* – Czech research project 1997-2002, Academia, 39-71.

Křivánek, R. 2003. Contribution of geophysical measurements for survey and protection of hillforts. In: M. O. Altan (ed.): Proceedings of the XIXth International Symposium CIPA 2003, *New Perspectives To Save Cultural Herritage,* Antalya (Turkey) 30 September – 04 October, 2003, CIPA Istambul, 389-391.

Křivánek, R. 2003. Magnetometric prospection of various types of large ditch enclosures (or fortifications) in Bohemia. Archaeologia Polona, vol. 41: 2003 (Herbich, T. (ed.): *Archaeological prospection - 5th International Conference on Archaeological Prospection*, Cracow 10.-14. 9. 2003), Warsaw, pp. 216-219.

Křivánek, R. 2005. Geophysical survey in the archaeologically univestigated parts of Czech oppida. In: S. Piro (ed.): Proceedings, Extended Abstracts - *6th International Conference on Archaeological Prospection*, Rome, Italy September 14-17, 2005, Institute of Technologies Applied to Cultural Heritage (C.N.R.), Roma, 17-20.

Křivánek, R. 2006. Application of geophysical methods for study of the real state of subsurface preservation of archaeological features or monuments – case study from Bohemia. In: ISA 2006, *36th International Symposium on Archaeometry*, 2 – 6 May 2006, Quebec City, 148.

Pavelka,K. 2007. Rectification of Petroglyphs with photogrammetrical methods, p.103-114, *Dresdener Kartographische Schriften*, Hrsg.B.Teichert and CH.Rust,, Nasca Symposium, HTW Dresden, Dresden 2007, ISSN 1436-0004

Pavelka,K., Svatušková,J., Králová,V.: Photogrammetric Documentation and Visualization of Choli Minaret and Great Citadel in Erbil/Iraq, CIPA congress, 1.-6.10.2007, Athens, Greece, 567-573

Integrated remote sensing techniques for the detection of buried archaeological adobe structures: preliminary results in Cahuachi (Peru).

N. Masini[1], E. Rizzo[2], R. Lasaponara[2], G. Orefici [3]

1 CNR-IBAM (Istituto per i Beni Archeologici e Monumentali), C.da S. Loja 85050 Tito Scalo (PZ), Italy
2 CNR-IMAA (Istituto di Metodologie di Analisi Ambientale), C.da S. Loja 85050 Tito Scalo (PZ), Italy
3 Centro de Estudios Arqueológicos Precolombinos (CEAP), Nasca, Peru.

ABSTRACT

In Cahuachi, (Nasca territory, Southern Peru) archaeological excavations performed during the last two decades have been unearthing adobe monuments related to a Ceremonial Centre dating back from the 6th century B.C. to the 4th century A.D. At the moment, the archaeological research, performed by an Italian-Peruvian mission (CEAP) directed by Giuseppe Orefici, is focused on two different issues: (i) one is aimed at completing the excavation in progress, in the sector which has been thought the core of the Ceremonial centre; (ii) the second one is the enlargement of the investigation to surrounding areas of the archaeological site.

Beginning from 2007 the two institutes of CNR, IMAA and IBAM, have been involved by CEAP, in order to provide a scientific and technological support for the archaeological research. The two different archaeological issues made necessary a multiscale and multisensor approach based on the integration of aerial, satellite and ground remote sensing technique.

This paper is focused on the jointly use of satellite Quickbird images and Ground Probing Radar for assessing the capability in the detection of archaeological adobe structures. GPR has been performed on a zone located near some unearthed temples in order to identify possible buried graves and walls to be excavated; satellite imagery has been experienced on a selected test area in order to assess their capability in detecting and mapping surface and sub surface archaeological features.

1. INTRODUCTION

The use of remote sensing technologies for the identification, mapping and interpretation of archaeological resources is an hot issue with important scientific and technological implications. The integrated use of remote sensing techniques is considered essential to meet the numerous and different archaeological demands, from the discovery of buried sites to the reconstruction of historical landscapes (Kvamme *et al.*, 2006).

Nevertheless, the use of remote sensing in archaeology for the detection of some type of archaeological features is sill an open question. It is the case of the adobe which had been widely used in Middle East, North Africa, Central and Southern America, for a long time to build domestic, fortified and religious settlements (Linford, 2006; Kvamme *et al.*, 2006). The relatively low geophysical parameter contrast between the buried adobe archaeological remains and the surrounding subsoil make difficult its detection from any type of remote sensing techniques.

In order to cope with such a difficulty , in this paper we experienced the use of both satellite QuickBird (QB) imaging and Ground Probing Radar (GPR). Their capability in the detecting archaeological adobe structures has been evaluated for Cahuachi (Southern Peru), where ongoing archaeological excavations performed during the last two decades have been unearthing adobe monuments related to a Ceremonial Centre, linked to Paracas and Nasca civilizations (Silverman 1993; Orefici 1992; Orefici 1993; Orefici & Drusini, 2003).
Archaeological investigations are currently performed by an Italian-Peruvian mission directed by Giuseppe Orefici. Two different issues need to be addressed: i) the localization of potential buried remains to support and orientate the excavation planning; ii) the enlargement of the investigation to surrounding areas of the archaeological site.

Such issues have been addressed : i) by using GPR for a zone located near some unearthed temples in order to identify possible buried graves and walls to be excavated; ii) by testing the capability of satellite imagery in detecting and mapping surface and sub surface adobe archaeological features.

2. STUDY AREA

Cahuachi is situated at an elevation of 365 m a.s.l. on a Pre-Montane desert formation in the drainage basin of Rio Grande (Southern Peru), characterized by a hot and arid climate with very little measurable rainfall recorded each year. This reflects on the hydrographical pattern composed of influent streams which flow for a few weeks in the wet season thanks to runoff from rains in the highlands (ONERN, 1971).

Geologically it is located on Quaternary sedimentary rock formations (that are riverine and riverine alluvial) of a tectonic depression (Ica-Nasca Depression). A few kilometres from the archaeological site are the Andean foothills, composed of Jurassic and Cretaceo formations (Montoya *et al.*, 1994).

Historically, the drainage basin of Rio Grande was characterized by a long human activity beginning from the Formative Period (Initial Period, 1800-800 BC; Paracas culture, 800-200 BC). Afterwards, in the Early Intermediate Period (200 BC-600 AD) this region flourished under the Nasca Culture, during Cahuachi was founded and developed.

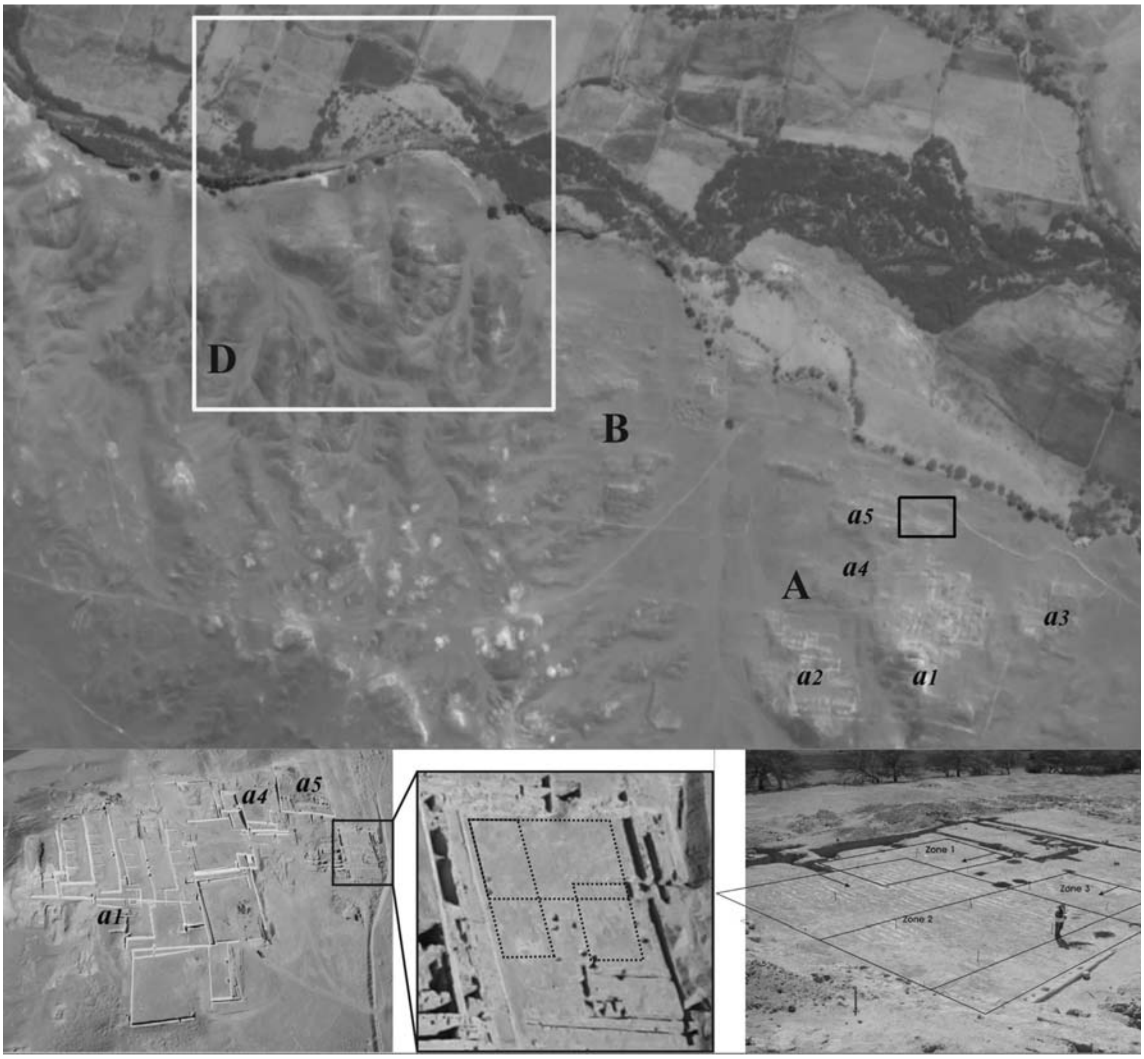


Figure 1. (Up) Study area. White box indicates the area investigated by QB imagery, named D; the black box locates the GPR test area. (Lower left) Detail of the Gran Piramide *(a1),* Templo del Escalonado *(a4) and the* Templo de Naranja *(a5). (Lower center and right) the area investigates by GPR.*

Cahuachi is believed to have been an important ceremonial centre (Silverman 1993; Orefici 1992; Orefici 1993) which served as a place of pilgrimage for the population living in the basin of Rio Grande. The archaeological evidences spread out on a large desolate area sited on the left of Nasca river, characterized by about forty mounds

The archaeological data recorded by means of excavations, trials and field surveys carried out in the last two decades, allowed us to identify five building historical phases, which reflect the functional and cultural evolution of the site, which was at the beginning a sort of sanctuary or Huaca. Then it became a ceremonial centre, later the Theocratic Capital of the Nasca state, and finally (300-400 A.D.), it was abandoned and covered with sand of the desert, after some destructive seismic and flash flood events

Up to now, about the half of the sector A has been brought to light. The excavations have completely unearthed and restored the so-called “la Grande Piramide (Orefici, 1983; see a1 in figure 1), a huge asymmetrical Pyramid. Whereas, a terraced temple (Templo del Escalonado; a5, figure 1) and a smaller pyramid (*Templo de Naranja*, a4, figure 1) are in advanced state of excavation. Sector A also includes another mound (*Monticulo*; a3 in figure 1), that has been partially unearthed and a terraced mound not still excavated (*Grande Templo*; figure 1, a2). Another sector, named B, was also investigated by means of field surveys which allowed to identify a certain number of mounds and platforms along with 3 sided enclosures.

This paper shows the results of investigations carried out by using satellite VHR-QB images and GPR on two test sites. One is inside the sector A. Herein GPR measurements were performed and QB imagery were employed for geo-referencing the prospected area. The other one, named D, is located at 300-500 mt Nortwest of the sector B, and was investigated only by using QB images.

3. SATELLITE BASED ANALYSIS AND RESULTS

For this study we used QB images QuickBird acquired on the 25th March 2005 (Catalog ID 90100100153B9E00). Two different superficial characteristics have been investigated: i) a desert area covered by alluvial deposit; ii) and a vegetated land. The investigations were performed considering both single spectral channels and numerical combinations. All of them were first investigated individually and then combined by using a data fusion algorithm in order to integrate the geometric detail of panchromatic and the spectral information of the multispectral images.

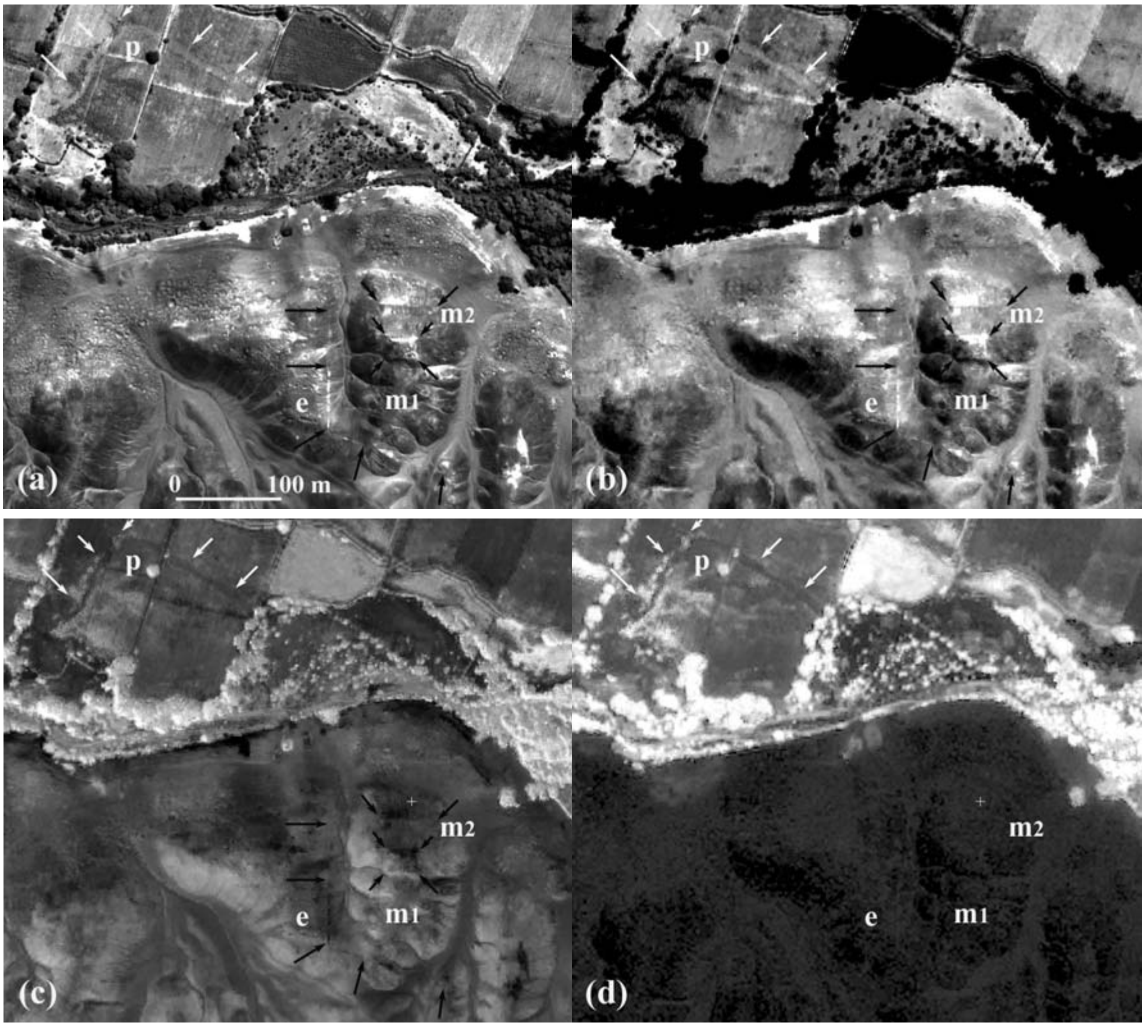


Figure 2. (a) QB panchromatic image; (b) red data fusion product; (c) first PCA component; (d) NDVI map. The QB images put in evidence a mound (m1), a platform (m2), an enclosure (e) in the arid area, and a palaeo river bed (p) in the vegetated surface.

In order to enhance the low contrast between the potential archaeological features and the surrounding area Normalized Difference Vegetation index (NDVI) and Principal Component Analysis (PCA) were used.

The NDVI has been successfully used in archaeological applications to enhance crop marks for both homogeneous vegetation covers and sparse herbaceous plants (Lasaponara & Masini, 2006) for satellite images acquired during different period of the year spring to summer, characterized by green or dried vegetation respectively. The PCA have been widely used of to enhance archaeological marks for both vegetated and desert area.

The visual inspection of the available data set (panchromatic, multispectral data fusion products, NDVI and PCA components), put in evidence i) a quadrangular plan mound with dimensions of about 22 x 32 m (see m1, figure 2) and ii) an underlying rectangular platform, with dimensions of about 30 x 58 m (see m2, in figure 2). The images also show linear marks (see e, in figure 2) originated by surface and shallow structures, thought to be the enclosure walls (perimeter 230 m) of the mound and platform complex, along the southern and western sides.

In the figure 2, we can observe that the enclosure seems to have been interrupted by a palaeo-stream bed. This suggests that in the past the enclosure was longer. Probably, it was destroyed by a flash flood event, occurred in the last phase of Cahuachi history (see section 2). As regards the vegetated area, traces of a palaeo-river bed are visible (see letter p and white arrows in figure 2).

The comparative visual inspection of the available dataset put in evidence that the panchromatic and the first PCA component provides more and better quality information for the arid setting; whereas the red datafusion product and NDVI were able to better emphasize the palaeo-river bed features in the vegetated area.

5. GPR PROSPECTIONS : ANALYSIS AND RESULTS

The GPR prospecting can be considered as a powerful tool for detecting and imaging shallow subsurface targets, such as stone and brick masonry, characterised by dielectric and conductive properties that are very different from those of the host medium (Piro *et al.*, 2003; Chianese *et al.*, 2004; Rizzo *et al.*, 2005). In case of adobe masonry, GPR can meet serious problem linked to the low resistivity and dielectric contrast between the buried wall and the sandy and clayey material which characterises the subsurface geology.

In this study, we experienced the GPR to detect potential buried adobe walls and graves near *Templo del Escalonado* and *Templo de Naranja* (see figure 1, up and low).

The GPR survey was made using the Subsurface Interface Radar (SIR) 3000 manufactured by Geophysical Survey Systems Incorporation (GSSI). The SIR 3000 has a digital control unit with keypad, VGA video screen and connector panel. The unit is backpack portable, requiring one or two operators, and the used antenna was the monostatic type 400 MHz (by GSSI). The GPR acquisitions were in continuous mode with a two-way time range of 40ns, and an interval band pass filter of 100-800 ns. The survey was acquired without a "wheel accessory" but a reference metre rule was located along each profile and marked at each meter. Therefore, a distance normalization to mitigate uncertainties on the antenna positions has been adopted. The ReflexW software has been used to process the data, the high quality of the traces requires only standard analysis techniques for data processing and to reduce the background noise (normalization, zero time correction, background removal processing).

The area was divided in three zone and several 2D GPR profiles were carried out in parallel direction (figure 1, lower right corner). Using the ReflexW software, a 3D GPR images have been produced.

The analysis of the 2D GPR radargrams allow us to estimate an average electromagnetic wave velocity by hyperbola analysis obtaining a value of 0.15m/ns. Therefore, the maximum investigation depth was around 1.5m.

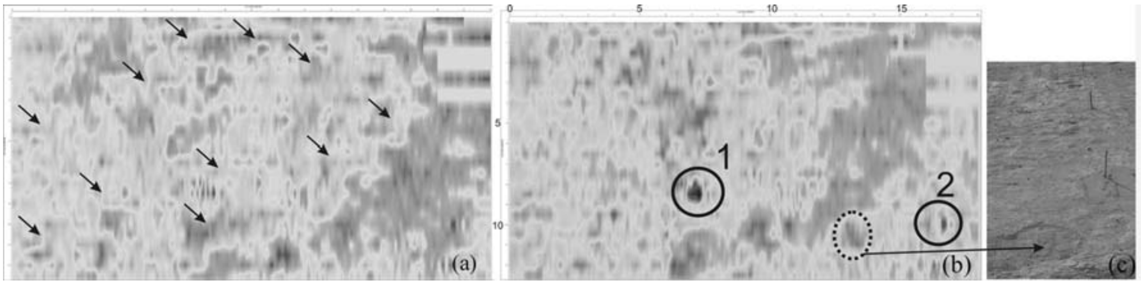


Figure 3. (a) slice at a depth of 0.20m obtained from several 2D radargramm carried out in the Zone 2. The black arrows indicate the top of buried adobe clay structure; (b) slice at a depth of 0.15m in the Zone 2. The black circles indicate the reflection with high amplitude associated to typical tombs with circular shape

The figure 3a is an example of GPR slice obtained by 2D radargramms carried out in the Zone 2. The Zone 2 has the dimension 18 x 13 mq and it was investigated by 26 profiles with a spacing of 0.5m. The slice has a depth of 0.2m (with the e.m velocity of 0.15 m/ns). The black arrows indicate the main reflections whose linear pattern orientation suggests the presence of adobe buried walls. Therefore, the observed electromagnetic signals could be associated to the top of these walls.

The figure 3b shows the slice of Zone 2 with a depth of 0.15m. In the image two interesting area are visible. The reflection with high amplitude visible at X=13m and Y=11m is the response of a tomb visible on surface (black arrow indicates it on the picture in figure X4) which was excavated and successively refilled. Therefore, the biggest reflections at X=7m and Y=8m and at X=17m and Y=10 indicated with a black circle could be associated to an unexplored tomb with a typical circular shape, which example is visible on the picture of figure 3c.

6. CONCLUSION

The use and the integration of multisensor and multiscale remote sensing technologies is highly desirable for supporting archaeological prospection. In this paper, satellite Quickbird (QB) images and Ground Probing Radar (GPR) have been experienced in order to assess their capability in detecting surface and subsurface archaeological adobe structures. Such an assessment was performed for two significant test areas selected in the Ceremonial Centre of Cahuachi in Southern of Peru.

In particular, satellite based investigation was performed for an area with different superficial characteristics: (i) deserted land and (ii) cultivated surface. For both the two cases, significant traces linked to past human activities and paleao-environment were extracted. For desert land, panchromatic and the first PCA component allowed to better enhance features related to an mound and platform along with 2 sided enclosure. For the vegetated surface, marks related to a paleao river bed were more visible from red data fusion product and NDVI.

GPR also proved to be capable in detecting buried adobe structures, in particular, it allowed to discover two unknown tombs and buried walls. The obtained results will be the basis information for the next excavation campaigns which is scheduled for November 2008.

REFERENCE

Chianese, D., D’Emilio, M., Di Salvia, S., Lapenna, V., Ragosta, M., Rizzo, E. 2004. Magnetic Mapping, Ground Penetrating Radar Surveys and Magnetic Susceptibility Measurements for the Study of the Archaeological Site of Serra di Vaglio (Southern Italy). *Journal of Archaeological Science,* 31 : 633-643.

Kvamme, K., Ernenwein, E., Hargrave, M., Sever, T., Harmon, D., Limp, F. 2006. *New Approaches to the Use and Integration of Multi-Sensor Remote Sensing for Historic Resource. Identification and Evaluation*, Report of SERDP Project SI-1263.

Lasaponara, R., Masini, N. 2006. Identification of archaeological buried remains based on Normalized Difference Vegetation Index (NDVI) from Quickbird satellite data, *IEE Geoscience and Remote Sensing Letters*, 3 (3): 325-328

Linford, N. 2006. The application of geophysical methods to archaeological prospection, *Report of Progress in Physics*, 69 : 2205-2257.

Montoya, M., Gracìa, W., Caidas, J. 1994. *Geologìa de los Quadrangulos de Lomitas, Palpa, Nasca y Puquio*, INGGEMET (Istituto Geologico Minero y Metallurgico), Lima.

ONERN 1971. *Inventario*, *Evaluaciòn, y Uso racional de los recursos Naturales de la Costa: Cuencas de los Rìos san Juan (Chincha) y Toparà*, ONERN, Lima.

Orefici, G. 1992. *Nasca. Archeologia per una ricostruzione storica,* Jaca Book.

Orefici, G. 1993. *Nasca: Arte e società del popolo dei geoglifi,* Jaca Book, Milano.

Orefici, G., Drusini, A. 2003. *Nasca: Hìpotesis y Evidencias de su Desarrollo Cultural*, Centro Italiano Studi e Ricerche Archeologiche Precolombiane, Brescia.

Piro, P., Goodman, D., Nishimura, Y., 2003. The study and characterization of Emperor Traiano’s Villa (Altopiani di Arcinazzo-Roma) using high-resolution integrated geophysical surveys. *Arch. Prosp.* 10 : 1–25.

Rizzo, E., Chianese, D., Lapenna, V. 2005. Integration of magnetometric, gpr and geoelectric measurements applied to the archaeological site of Viggiano (Southern Italy, Agri Valley- Basilicata). Near Surface Geophysics, 3,13-19.

Silverman, H. 1993. *Cahuachi in the Ancient Nasca World,* University Of Iowa Press.

Rizzo, E., Chianese, D. and Lapenna, V.: Integration of magnetometric, gpr and geoelectric measurements applied to the archaeological site of Viggiano (Southern Italy, Agri Valley- Basilicata). *Near Surface Geophysics*, 3 : 13-19, 2005.

Airborne and ground remote sensing for archaeological applications: landscapes and mines in Gargano area (Italy)

R. Salvini[1], F.M. Martino[1], A. Galiberti[2], M. Tarantini[3], F. Mantovani[4]

1 Earth Sciences Department and Centre of Geotechnologies, University of Siena, via Vetri Vecchi 34, 52027 San Giovanni Valdarno (Arezzo - Italy), salvinir@unisi.it
2 Department of Archaeology and Arts History, Prehistory Section, University of Siena, via delle Cerchia 5, 53100 Siena (Italy), galiberti@unisi.it
3 Department of Archaeology and Arts History, Prehistory Section, University of Siena, via delle Cerchia 5, 53100 Siena (Italy), tarantini@unisi.it
4 Centre of Geotechnologies, University of Siena, via Vetri Vecchi 34, 52027 San Giovanni Valdarno (Arezzo - Italy), mantovani3@unisi.it

Keywords: flint, mines, photogrammetry, resistivity

ABSTRACT.
This paper illustrates some results of an Italian National Research Project "PRIN2005", devoted to study both features of a prehistorical mining landscape and underground mines - not evident, or partially evident, on surface.
The context of the project is the Promontory of Gargano (South-Eastern Italy, Foggia), where the extraordinary availability of flint is associated with evidence of numerous extraction complexes (underground mines). According to the available data, the mines cover a time-span of almost three thousand years; among them, the most important is the Defensola, a mine- the most ancient in Europe- active from roughly 5.800 b.C.
Differently from other European prehistoric mining complexes, in Gargano, mines generally open onto slopes with a convex morphology and have often produced extremely large conoidal spoil heaps outside.
Two different methods of investigation have been used. The first method was based on digital aerial photogrammetry in order to find natural and archaeological features of prehistorical landscape. Starting from present and historical geo-morphological evidences, thanks to the stereo and photo interpretation that have shown earthworks and soil-marks, it was possible to recognize geological features interpreted as evidence of palaeodrainage and ancient coastline. The integration with historical references and geological researchs through a GIS allowed to join different dataset in a way to highlight the spatial and temporal variations and to produce thematic cartography.
The second level of investigation moves by geophysical surveys. These latter allowed to determine the internal layout of each mining structure, where only the entrance is known. Moreover, geophysical prospecting allowed to verify the presence of new mining structures, in presence of one or few vertical shafts, generally as a part of larger mining complexes.

1 THE GEOLOGICAL AND ENVIRONMENTAL CONTEXT

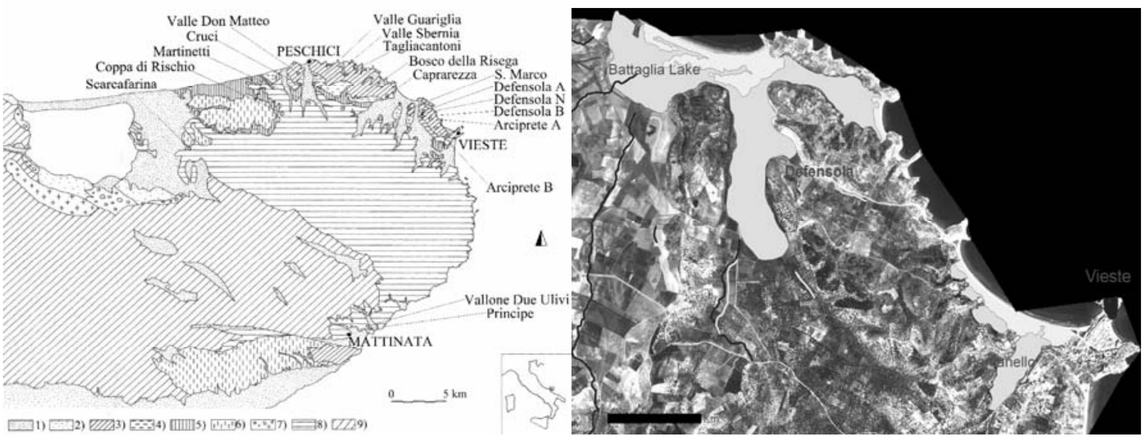
The Promontory of Gargano is located in the Southern part of the foreland area of Apennine-Dynaric system (Funicello *et al.*, 1988; Patacca & Scandone, 2004) in Eastern Apulia (South-Eastern Italy).

The geology of the area is characterized by a cyclical sequence of carbonatic platform sediments (tidal and subtidal flat) and, in the Eastern peripheral part, by basin carbonatic limestones that underwent a sedimentation process compensated by tectonic subsidence (Bosellini *et al.*, 1993). From the Neogene, the area was interested by an extended and continuous raising (Doglioni *et al.*, 1996; Gambini & Tozzi, 1996).

This scenario developed to the actual setting, causing, moreover, extended karst phenomena (Pieri & Ricchetti, 1999). At the top of the meso-cenozoic geologic formations of the stratigraphic sequence, the carbonatic-selciferous lithologic units of the Cretaceous-Eocene formations (particularly the carbonatic limestones so-called "Maiolica", "Scaglia" and "Peschici Limestones") outcrop. Due to a weak tectonic deformation the flint contained within these, is often found in a no-jointed undisturbed state. The research work has been mainly concentrated upon the North-Eastern coasting area of the Promontory, where many evidences -leading back to human activities about the prehistorical period- can be found (figure 1).

Generally speaking, two different kinds of extraction processes can be identified in the Gargano area, closely linked to the geological setting of the formations. Where the formations are compact, excavation proceeded by removing individual limestone layers in their entirety. Depending on the thickness of the layers, a sufficient number of these were removed to obtain a floor-ceiling height allowing excavation to proceed. This height rarely exceeds 60 cm. This excavation method used the joins between layers as guidelines for the removal of the layers, thereby creating structures with a characteristic flat roof. Therefore, differently from other European prehistoric mining complexes, in Gargano mines often open onto slopes with a convex morphology, and have often created large conoidal spoil fans outside (e.g. Defensola A).

Vertical access to flint-bearing formations is the only option where the morphology is flat, as in large areas of central Europe. Extraction using vertical shafts is also the only option in formations which are strongly affected by tectonic activity, where it would be impossible to carry out sub-horizontal excavation safely.



Figures 1/2. (1) Geological map with showed flint mines. 1 Quaternary; 2 Mio-Pliocene; 3 M.Saraceno sequence; 4 Scaglia; 5 Scisti a Fucoidi; 6 M.Acuto e M. S.Angelo formations; 7 Breccia di Cagnano; 8 Maiolica; 9 M.Sacro sequence (geological data from Bosellini & Morsilli, 2002).(2) Results of the multitemporal stereointerpretation of the North-Eastern coasting area of the Promontory

Hitherto, 18 complexes for the extraction of flint have been identified, discovered with their original entrances or following earthmoving for construction or road works. Nine complexes have now been attributed to specific contexts (Galiberti, 2005); it is now possible to date the beginnings of extraction activities to the early VI millennium b.C. (Defensola A: Utc 1342 6990±80 BP, cal. 2σ 5993-5652 b.C.), coinciding with the Neolithization of south-eastern Italy; the mining phenomenon terminates at the end of the Copper Age (Defensola B: Beta 171597 4050±40 BP, cal. 2σ 2850-2820, 2670-2470 B.C.).

Looking at the area from an environmental point of view, the actual landescape looks heavily modified, because of the presence of tourist industry. Through the analysis of the historical cartography and toponymy, it was possible to recreate a recently-disappeared environmental context. Many toponyms bring back to the presence of lost moist areas, such as "Pantanelle, Pantano di Santa Maria, Palude di Sfinale and Padula". Between the XVI and the XVIII centuries, the historical cartography shows the presence of a dried-up lake, named "Battaglia" and located in the Northern area of Vieste; its disappearance is interpreted as a consequence of the process of heavy deforestation that took place in the period between the XIX and XX centuries.

Palaeo-environmental researches, carried out by the University of Bari, have shown that the area of the Battaglia Lake, placed at the foot of Defensola mine, underwent a series of changes and different phases of life. During the Neolithic Age, when flint-mines were still active, the area was characterized by the presence of a pebbly beach, a sort of bay, opened to the sea. During the following centuries, the close basin of the Battaglia Lake gradually formed; its presence is attested by radiometric dating starting from the IX century a.C. and its vanishing took place during the XIX century (Caldara *et al.*, 2005.).

2 METHODS AND RESULTS

2.1 *Airborne remote sensing*

A first level of investigation concerns the identification of specific geological features from the digital aerial stereorestitution. The starting point was the conjecture that a stereoscopic vision emphasizes earthworks, meaning small altimetrical variations and other anomalies, otherwise imperceptible. Through the ERDAS™ Imagine 9.1 StereoAnalyst module, small depressions have been identified in photos related to the year 1954; these ground depressions, on the contrary practically invisible in the orthophotos of 2004, have been led to palaeo-channels. Moreover, in stereoscopy, it was possible to identify alluvial fans, palaeo-lakes and coastal dunes, separated from the sea by rises in the ground sometimes of only few metres(Fig.2).

The identified anomalies have been studied more in deep by using the ESRI™ ArcGIS 9.1 software, laying the image over the digital elevation model of the ground and creating three-dimensional representations. To this phase, the identification of soil marks and crop marks in all the panchromatic photos concerning 1992 and 1996, such as in colour orthophotos concerning 2004, made available by the Gargano National Park, followed. The comparison of images-related to different years shows that the photos concerning 1955 are better interpretable because of a widespread agricultural activity, that cleared vegetation leaving the rock to be easily identifiable from remote, and because of the absence of recent anthropic impact that modified the area due to urbanization.

The river beds of streams that were still active in 1954 and were dammed into artificial canalization in 1992 have been also stereo-interpreted. This was possible thanks to the identification of earthworks that represented the river bed of streams, cutting into the geological substratum. These elevation variations made possible the identification of the Battaglia Lake limits. This one occupied the costal inner part and during the Neolithic Age it bordered the Defensola hill where flint mines were active. Other lake-basins (between the Battaglia Lake and the actual Vieste built-up area) have been identified through the stereoscopic investigation(figure 2).

These results have been assessed by the comparison with stratigraphic data regarding the area of Battaglia Lake that confirm the presence of fluvial and lucustrine deposits(Caldara *et al.*, 2005).

2.2 *Ground proximal sensing*

Because mines consist of one or more communicating chambers, containing pillars of untouched rock and/or heaps of excavation debris, probably used as support structures, a level of investigation moved by geophysical surveys, oriented to determine the internal layout of each mining structure of which only the entrance is known (e.g. Arciprete, Principe localities).

The application of non-excavation methods is recognized as an important element in mining site research (Budziszewski, 1990) and in particular the geophysical methods have been successfully used in other Neolithic mining complexes (Herbich, 1997; Leopold, 2004; Borkowski et al., 1991). The archaeological features of the area suggested to perform a geophysical survey by using the method of the resistivity technique. Two dimensional apparent resistivity investigations were performed by an automatic device (Abem^{tm} Terrameter SAS 1000) that supports 64 electrodes.

The Schlumberger acquisition with a high *n* factor was chosen because it is sensitive to both horizontal and vertical structures. From this acquisition, pseudo-sections were obtained. Then, computer modelling helps to interpret geoelectrical data by using inverse methods (Res2Dinv Geotomo^{tm} Software) getting images of the subsurface resistivity from the pseudo-sections. The two dimensional imaging of the ground, called Electrical Resistivity Tomography (ERT), gives information about the distribution of the resistivity in the ground (Loke, 2004).

Four 2D resistivity investigations were executed in Defensola A site. At the top of the hill, three 2D electrical imaging surveys (line 1=50,4m of length, line 2=63m and line 4=94,5m) were carried out. Another 2D resistivity survey was performed along the hill's slope (line 3=63 m), crossing the rubble fan (Fig.3). The ERT results on the lines 1 and 2 show a homogenous layer of limestones ($\rho > 200\ \Omega m$) up to about 3 m of depth. From this layer up to the maximal depth (about 10 m), it is possible to note another homogeneous zone with low resistivity values ($\rho < 60\ \Omega m$), probably caused by larger content of water in the porous. The line 3 starts from the higher terrace and cuts perpendicularly the lines 1, 2 and the fan; the ERT investigates up to 10 m of depth. Whereas the terraces shapes a horizontal surface, the same homogeneous layer of limestone with high resistivity values ($\rho > 200\ \Omega m$) are present, while lower resistivity values are registered in the lower part of the section. In this tomography the presence of the excavation rubble is emphasized by higher resistivity values ($\rho > 300\ \Omega m$): probably the fan is placed on the top part of a wider layer of limestone and it is composed by the same material. All the data collected along the lines 1, 2 and 3 can be interpreted in the local geological framework and it is not evident any anomalous signal having reference to mining human activity.

The ERT along the line 4 shows the same resistivity setting: under a limestone layer 3 m thick ($\rho > 200\ \Omega m$), the presence of water in the porous reduces the resistivity values for the investigated section to a depth of 16 m ($\rho < 60\ \Omega m$). The only singularity in this homogeneous scenario is represented by a spot of very high resistivity ($\rho > 1000\ \Omega m$) located 15 m underground. This confined area is placed 56 m far away from the left boundary of the unvegetated area at a depth of 8 m from the terrace where the fan is placed.

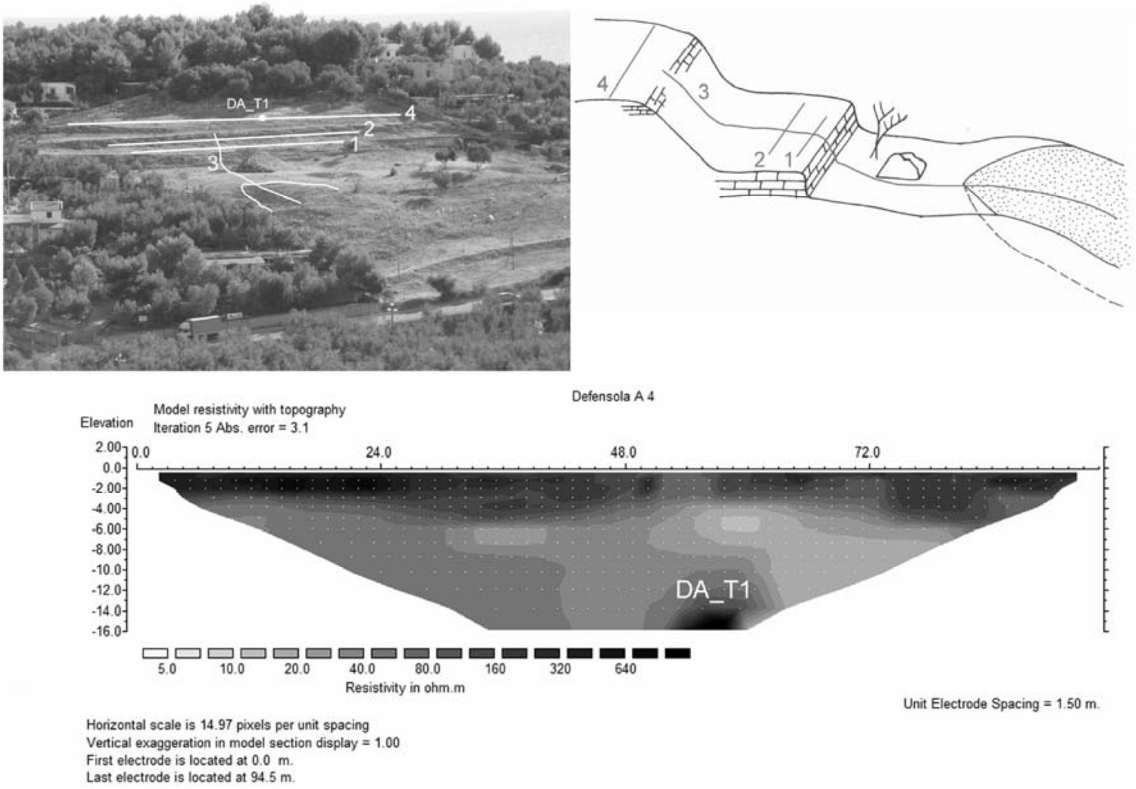


Figure 3. Defensola A. The 4 lines indicate the geophysical surveys. At the middle a scheme of the hill's side and of dumps fan. At the bottom the electrical tomography number 4 with the anomalous signal in dark grey.

The Defensola B site is characterized in one case by a vertical shaft and small tunnel that encloses a huge flint nodule with an estimated diameter of about 1,5 m. The area is fully vegetated and sometime the bush represented a hindrance for the surveys. An area of about 800 m^2 was investigated by four 2D electrical imaging surveys (line 1=31,5 m, line 2=31,5 m, line 3=31,5 m, line 4=31,5 m). In all the acquisitions an homogenous (humid) soil appear clearly: in the ERT it looks like a thin layer with resistivity values lower than 100 Ωm. The big flint nodule near the pit represented a good opportunity to test the instrument on this kind of "rare" target: it gives an impressive signal and the resistivity exceeds 10^4 Ωm on ERT B1 and B4. This extremely compact rock is set in a limestone layer about 2 m thick ranged for all the investigated areas. A superficial (0,5 m) high resistivity values ($\rho > 3000$ Ωm) appears exactly on the cross point between ERT survey B2 and B4: below this, ERT reveals an anomalous spot with low resistivity value ($80 < \rho < 100$ Ωm). This problematic patchwork could be interpreted in many anthropic ways, but surely it represents a purposeful geologic anomaly. The high resistivity spot ($\rho > 8000$ Ωm) on ERT B3 at about 1 m depth cause ambiguity in the interpretation of the event. In the same ERT a peculiar target localized 1 m underground produces the lowest resistivity value ($\rho < 60$ Ωm) of the whole area and it could be hardly interpreted in geological way because of its high and evident contrast with the surrounding resistivity values.

The surveys in Principe site were focused around the vertical access to an ancient mine. The four 2D electrical imaging surveys investigate four sections 31 m long, that reach about 4,5 m of depth. The results match and confirm the hypothesis of the archaeologist that explored the first part of the tunnel. The resistivity models show high values ($\rho > 2000$ Ωm) whereas the section intercepts the cavity.

This project sprang from the conviction that an understanding of the mechanisms governing the process of acquiring raw materials, often difficult to document, represents a key element in the study of the economic, social and behavioural dynamics of prehistoric societies. In order to attain this purely archaeological objective by reconstructing aspects of human activity, different methodologies, proper to the fields of archaeology, geology and applied geotechnologies have been adopted. The use of an integrated approach of this type in itself represented an inner objective of the research project, in this case of methodological nature. The results from aerial digital photogrammetry and geophysical prospecting demonstrated that only through an interdisciplinary approach of this type, which in this case has been tested ex novo, it is possible to attain the primary objective. The described applied technologies allowed to improve the knowledge on both a geomorphological level to identify new sites, and on the level of individual complexes (geophysical studies were used to determine their extent), the archaeological aspects of which are under investigation.

Nevertheless, many ambiguities in the interpretation of the data, especially for the geophysical approach, are still there; many times, high resistivity values left the doubt to be interpreted as cavity, natural or kart. Targets producing the lowest resistivity value could be hardly explained by the geological setting because they are evidently in contrast with the surrounding resistivity values. For these, additional fieldwork and archaeological studies are necessary.

3 REFERENCES

Annan, A.P., 1996. Transmission dispersion and GPR, *J. Environ. Eng. Geophys* v. 0, n. 2, pp. 125-136.

Borkowski, W., Migal, W., SalaciNski, S. & Zalewski, M., 1991. Possibilities of investigating Neolithic flint economies, as exemplified by the banded flint economy, *Antiquity*, 65, pp. 607-627.

Bosellini, A., Neri, C. & Lucani, V., 1993. Guida ai carbonati cretaceo-eocenici di scarpata e di Bacino del Gargano (Italia meridionale). *Annali Università di Ferrara, Sezione Scienze della Terra*, vol. IV, p. 77.

Bosellini, A. & Morsilli, M., 2002. Il Promontorio del Gargano. Cenni di geologia e itinerari geologici, s.l..

Budziszewski, J., 1990. Remarks on methods of studying prehistoric areas of flint exploitation, in Séronie-Vivien, M.R. & Lenoire, M. (eds.), *Le silex de sa genèse à l'outil*: Cahiers du Quaternaire 17, Paris, pp. 217-223.

Caldara M., Caroli I., Gravina A., Simone O., 2005. Ricostruzione dell'ambiente fisico nei pressi della Defensola(Vieste).*Atti del 25°Convegno Nazionale sulla Preistoria-Protostoria e Storia della Daunia*. San Severo,pp.57–79.

Davis, J. L. & Annan, A. P., 1989. Ground-penetrating radar for high-resolution mapping of soil and rock stratigraphy, *Geophysical Prospecting* v. 37, pp. 531-551.

Di Lernia S. & Galiberti A., 1993. Archeologia mineraria della selce nella preistoria. Definizioni, potenzialità e prospettive della ricerca. *Quaderni Dipartimento di Archeologia e Storia delle Arti, Sezione archeologica – Università di Siena*.

Doglioni, C., Tropeano, M., Monelli, F. & Pieri, P., 1996. Middle Late Pleistocene uplift of Puglia: an "anomaly" in the Apenninic foreland. *Mem. Soc. Geol. It.*, vol. LI (1), pp. 101-117.

Funiciello, R., Montone, P., Salvini, F. & Tozzi, M., 1992. Caratteri strutturali del Promontorio del Gargano, *Mem. Soc. Geol. It.*, vol. XLI, pp. 1235-1243.

Galiberti, A., 2005. *Defensola. Una miniera di selce di 7000 anni fa*, Siena.

Gambini, R. & Tozzi M., 1996. Tertiary geodynamic evolution of te Southern Adria microplate, *Terranova*, vol. VIII, pp. 593-602.

Herbich, T., 1997. The electro-resistivity survey of the "Krzemionki" mining complex, Poland. Problems and results, in Ramos-Millan, A. & Bustillo, M. A. (eds.), *Siliceous Rocks and Culture*: Editorial Universidad de Granada, Granada, Spain, pp. 303-314.

Leopold, M. & Völkel, J., 2004. Neolithic flint mines in Arnhofen, southern Germany: a ground-penetrating radar survey, *Archaeological Prospection*, 11(2), pp. 57–64.

Loke, M.H., 2004. Electrical imaging surveys for hydrogeological, environmental and engineering studies, *Geofluid*, Piacenza.

Morsilli M. & Bosellini A., 1997: Carbonate facies zonation of the Upper Jurassic – Lower Cretaceous Apulia Platform margin (Gargano Promontory, southern Italy), *Rivista Italiana di Paleontologia e Stratigrafia*, 103, pp. 193-206.

Musson C.,Palmer R.,Campana S., 2005. *In volo nel passato. Aerofotografia e cartografia archeologica*. Florence.

Patacca, E. & Scandone, P., 2004. The Plio-Pleistocene thrust belt-foredeep system in the southern Apennines and Sicily (Italy), *Geology of Italy*, special vol. of the SGI for the 32 IGC, Florence.

Pieri, P. & Ricchetti, G., 1999. *Guide geologiche regionali, Puglia e Monte Vulture*: Società Geologica Italiana, I parte.

Tarantini M., 2006. Le miniere neolitiche ed eneolitiche del Gargano. Tecniche estrattive e dinamiche diacroniche, *Atti della XXXIX r.s. IIPP,* Florence, vol. I, pp. 343-353.

Weisgerber G., 1999. *5000 Jahre Feuersteinbergbau. Die Suche nach dem Stahl der Steinzeit*, Bochum.

Airborne and satellite multispectral imagery at the Etruscan site of San Giovenale, Blera (Lazio) – Preliminary results

Y. Backe Forsberg[1], R. Holmgren[2], A. Lanorte[3], R. Lasaponara[3] , N. Masini[4]

1 Istituto Svedese di Studi Classici a Roma, Via Omero 14, I-0019, Rome, Italy, forsberg@isvroma.org
2 ARCDOC, Djurgårdsgatan 38, 582 29 Linköping, Sweden, richard.david@swipnet.se
3 CNR- IMAA, C.da S.Loja – 85050 Tito Scalo (PZ), Italy lasaponara@imaa.cnr.it
4 CNR- IBAM, C.da S. Loja, 85050 Tito Scalo (PZ), Italy. n.masini@ibam.cnr.it

Keywords: thermal, near infrared, QuickBird, ultralight plane, Etruscan

ABSTRACT This paper is focused on the preliminary results obtained from the 2007 archaeological campaign carried out in the framework of a Swedish-Italian project aimed at (i) verifying Etruscan remains on the Vignale plateau (San Giovenale, Blera) and (ii) placing them in a landscape-archaeological perspective. This aerial/satellite project (previous a land-survey/excavation undertaking) at San Giovenale, delivers a more comprehensive understanding of the site as a much larger unit than earlier expected. In addition to the 2007 photographic approach, the use of a modified ultra-light airplane, flown by the team itself became a new experience and natural tool during our daily work. The use of improved small aircrafts and digital photographic equipment, opens up for alternative and valuable archaeological results without starting the field machinery with time and cost consuming trial excavations. The integration of the various data set, such as satellite scene and digital photographic techniques thermo-, near infrared- and conventional-photographs, enabled the identification of a number of unknown structures. The possibility of having a small plane for direct use besides digital photographic equipment allowed us to evaluate and test various techniques immediately. The results of the land-survey have furthermore revealed traces of structures both on top of and in the immediate surroundings of the plateau. These findings suggest a settlement of immense importance.

1 INTRODUCTION

The Swedish-Italian collaboration, still in progress, is a multidisciplinary research project developed with remote sensing experts and archaeologists, which aims to produce a comprehensive study in which San Giovenale is the focal point. The excavations and surveys from 1870s, 1950s -2006 in and around the ancient Etruscan settlement of San Giovenale, Blera, have revealed a centre of immense importance for the understanding of the Etruscan culture. Its development from later Bronze Age communities to Late Etruscan period is well attested (*Etruscan culture,* 1962; *Materiali e problemi,* 1984).

Although lavishly published in monographs throughout the years, many problems regarding the site have still to be investigated. A recent study on the bridge complex *i.e.* opens up new questions (Backe-Forsberg, 2005). One of these questions concerns to where about the bridge was leading after departing from the area of the Etruscan main acropolis. Roads and ramparts are leading towards the less studied high plateau of Vignale, in shape and dimension resembling the acropolis. Besides trial soundings and ground inspections, an attempt to better grasp and understand various visible and possibly hidden structures yielded for an aerial study. This study of 2007 did not only wish for better knowledge of Vignale itself, but also wanted to evaluate the efficiency of bringing the ultra-light airplane into an archaeological venture of this kind. Not the least was the possibility to land and start close to the site time efficient. With one of the pilots (Richard Holmgren), being an archaeologist in the team, a better understanding and easiness of which entities to address focus upon was facilitated.

2 RESEARCH AREA

The research area covers the Vignale plateau (see figure 1 a and b) show the, which is surrounded by the Etruscan habitation areas on the acropolis cliff, the Borgo and the many neighbouring necropolis. In 1959 and 1960 the western part of the plateau was surveyed and excavated by members of the Swedish Institute, who unearthed foundations of Hellenistic houses and cellars and eight Archaic wells (only two of them were fully explored) (*Etruscan culture*, 1972). A monumental foundation of tufa ashlars was discovered in the western part of the plateau similar to temple foundations excavated at Pyrgi and Tarquinia (Backe-Forsberg 2005). The trial trenches with this particular structure is clearly seen in the aerial photos taken by the Military Geographical Institute in Florence in 1960 and in 1961 in order to produce a topographic map on scale 1:1000 (*San Giovenale* 1:3. 1967). According to the excavators the Vignale hill was highly important and worth to be more fully explored but due to economical factors these investigations could not be concluded. However, the discovery in 1959-60 of the remains of an Etruscan bridge on the northern slope connecting the Vignale plateau with the surrounding hills, supported the conclusion previously made the excavators (Forsberg 1984, Backe-Forsberg 2005). Parts of this crucial material have been superficially presented in a doctoral thesis by Backe-Forsberg 2005.

A renewed interest in San Giovenale and Vignale as well as the need of binding together the already studied remains from 1959-1960, a land survey was initiated in February/March 2006 and an aerial investigation during the end of May in 2007 by members of the *Vignale Archaeological Project* (VAP). The aim of our initiated projects was to identify the remains related to the plateau which extends southeast of the familiar castle-rock of San Giovenale and to place them in a landscape-archaeological perspective. This wider approach of San Giovenale depicts a much larger unit than earlier expected. The vast and new material found in 2006 includes mapping of newly documented road systems, protective wall structures, ramps and agricultural installations. The results inspired to the aerial survey in 2007.

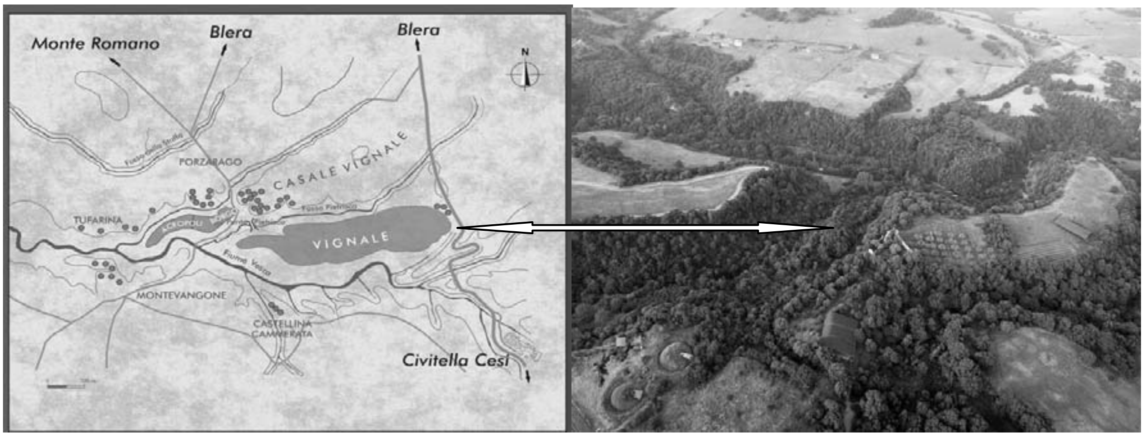


Figure 1. (Left) Map (Courtesy of the Soprintendenza per i Beni Archeologici del Lazio) and aerial photo (right) of the Vignale plateau

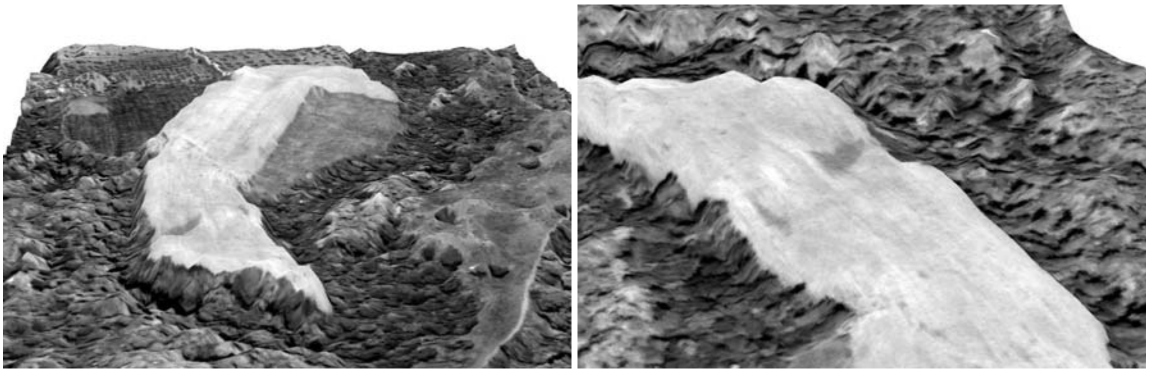


Figure 2 shows (left) a satellite based 3D visualization and (right) detail of the Vignale plateau

3 DATA SET AND ANALYSIS

3.1 Satellite QuickBird images

QuickBird is the commercial satellite that provides the highest spatial resolution of multispectral images. It has panchromatic and multispectral sensors with resolutions of 61-72cm and 2.44-2.88m, respectively, depending upon the off-nadir viewing angle (0-25 degrees), The panchromatic sensor collects information at the visible and near infrared wavelengths and has a bandwidth of 450 – 900 nm. The multispectral sensor acquires data in four spectral bands from blue to near infrared (NIR). Table 1 shows the band width of the QuickBird spectral channels. The QuickBird images adopted for this study [catalogue n 90100100132D8200] were acquired on 12 luglio 2003, at around 9.52 pm with an off nadir view 1.44.

Both panchromatic and multispectral satellite imagery were used for extensively mapping and reconstructing the ancient landscape and settlements. To this aim the data were processed both (i) for better understanding the complex relationship between the ancient settlements and the surrounding environment (landscape archaeology) (ii) and for identifying even very small structures.

Figures 2 a and b show a satellite based 3D view of the Vignale plateau. Results from both panchromatic and multispectral satellite analysis put in evidence the presence of spatial anomalies with (i) punctiform and (ii) linear shape of potential archaeological interest. Figure 3 shows the QB and the RGB (R=Red, G=NIR, B=PAN) and the panchromatic image. Red circles indicates some of the detected punctiform anomalies. All the features identified with satellite images were later investigated using the airborne-based data set. In particular, this study focused punctiform anomalies.

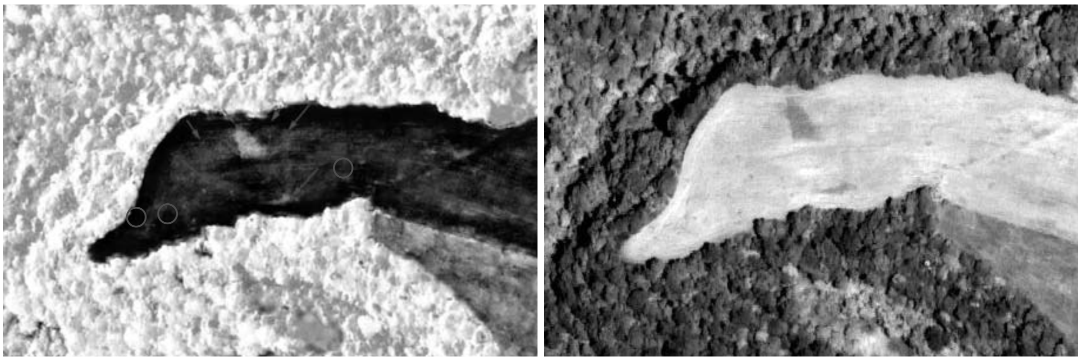


Figure 3 (Left) QB RGB (R=Red, G=NIR, B=PAN); (Right) Panchromatic image. On the left red circles and arrows indicate some spatial anomalies of potential archaeological interest.

3.2 AIRBORNE DATA

Conventional photography was utilized for landscape aerial photographs in general but above all to detect variations in vegetation cover and soil types generated from underlying structures – that is, soil- shadow and crop marks. Air near-infrared (NIR) and thermal pictures were also used over the study area. The NIR pictures were produced by using an ordinary Nikon DSLR-camera, rebuilt for our purpose. Digital imaging sensors are as sensitive to infrared light as to visible light. To stop infrared light from contaminating the images a hot mirror filter is placed in front of the sensor which blocks the infrared part of the spectrum while still allowing the visible light to pass. This filter was removed and replaced with a custom manufactured infrared filter, which gives a much faster exposure which is essential in a shaky plane. Both colour and black & white images were taken to cover the NIR spectral channel, which has a potential to further enhance vegetation marks affected by underlying structures.

The NIR colour photographs are still under processing hence the black and white NIR images produced a much clearer and distinct version compared to conventional black and white photographs. This was useful in defining various, and from the ground, already visible structures. However the greyscale of the NIR images were very helpful in detecting early trial soundings from the late 1950´s. These areas showed a darker colour scale and could therefore be put in relation to early described features, but also in relation to the promising hidden structures shown in the thermal images. In the 2007 aerial survey, using either of the NIR techniques, no new features could be determined with high reliability.

The thermal pictures were taken by using a thermo-camera, which exploits the thermo-graphy to provide thermal mapping of investigated surfaces. Surface thermal discontinuities, even on a small entity, may provide useful information in order to find the presence of different materials or hidden structures. The thermo-camera provides a thermal map showing warmer or colder regions according to the surface types, the presence of discontinuity or hidden structures. In the presence of hidden structures, such as walls or ditches, it is expected that the surface temperature would be affected by their presence, resulting in a measurable temperature increase or decrease in value. The interpretation of thermographical maps depends on the radiation wavelength, temperature and characteristic surface properties (emission, reflection and absorption). In order to perform “thermal data analysis” the primary component to be taken into account is the emission, which is dependant on surface temperature. In order to improve the analysis, the reflection component should be minimized as much as possible. In the current survey, to minimize the reflected components and maximize thermal emission, the flight survey was taken close to sunset thus facilitating the identification of traces of potential hidden archaeological remains.

As seen in the pictures (figure 3), the left thermal image indicates several wells of which some perfectly matches already studied items from land surveys performed on Vignale. A more detailed study of the thermo images reveals that these follows a lined pattern in the directions N-S, E-W. This can suggest an ancient layout with planned housing. The wells are also situated in an area with dense remains of building debris and shards, also reflected as a “warm” defined area (possibly superficial debris from housing) in the far end of the right photo in figure 1. Looking at the right thermal image, in the same figure, we see another cluster of presumed building remains. This area is connected with the above described area by a possible road. The cluster seems to comprise several buildings orientated in a large square. Early soundings have revealed a large cistern and a house foundation within this spot. The large cistern can bee seen as a larger dark square in the upper left corner of the cluster

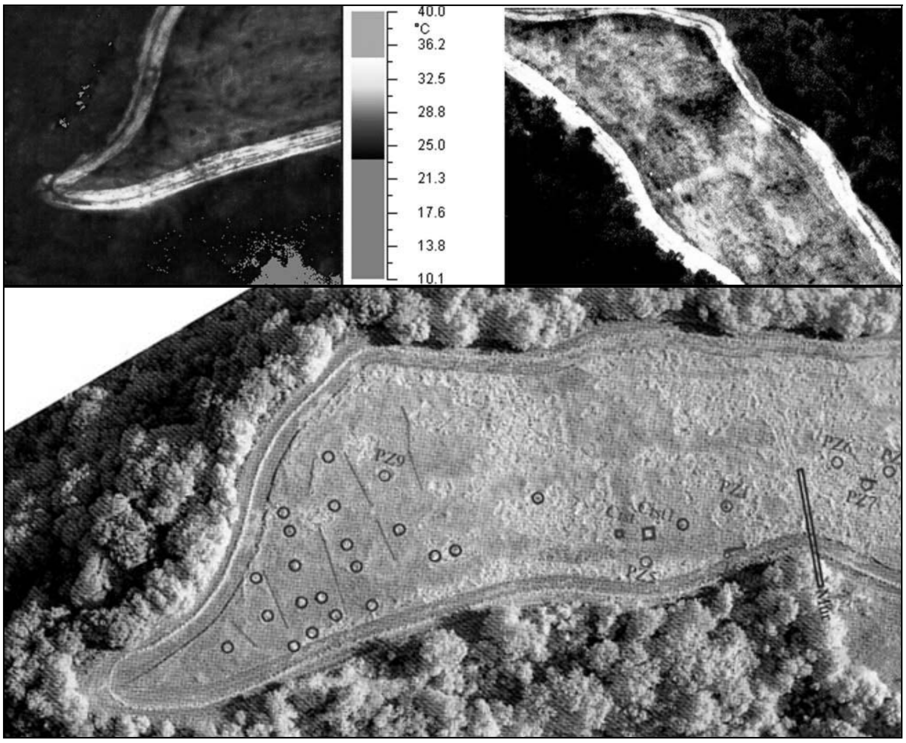


Fig 3.(up) Two examples of thermal photography used over the far western part of the Vignale plateau. (bottom)The NIR photograph shows a more comprehensive view of the entire tip of the Vignale habitation area. Two distinctive areas of possible hidden monumental structures are here connected by a shallow land strip, possible a road.

4 FINAL REMARKS

This paper presents the preliminary results obtained in the framework of a Swedish-Italian collaboration project, still in progress, aimed at (i) verifying Etruscan remains on the Vignale plateau (San Giovenale, Blera) and (ii) placing them in a landscape-archaeological perspective. The project is focused on the use of different aerial/satellite data source. In addition to the satellite scene and classic photographic approach, the experienced the use of a modified ultra-light airplane flown by the team itself. This became a new experience and natural tool during our daily work and opens up for alternative and valuable archaeological results without starting the field machinery with time and cost consuming trial excavations. When combining the various digital photographic techniques such as thermo-, near infrared- and conventional-photographs, we have been able to identify a number of unknown structures. The possibility of having a small plane for direct use besides digital photographic equipment allowed us to evaluate and test various techniques immediately. The cost effective plane and the digital apparatus makes this kind of venture a very useful and effective approach in many upcoming projects.

5 REFERENCES

Backe-Forsberg, Y. 2005. *Crossing the Bridge. An Interpretation of the Archaeological Remains in the Etruscan Bridge Complex at San Giovenale, Etruria.* Uppsala, diss).

Backe-Forsberg, Y., Holmgren, R., forthcoming. *An Etruscan twin settlement at San Giovenale, Blera - Structural analyses and dating of the Vignale plateau.*

Forsberg S. 1984. ‘Il complesso del ponte sul Fosso Pietrisco’, *Materiali e problemi. San Giovenale. Atti del Simposio all'Istituto svedese di studi classici a Roma*, *6 aprile 1983* (ActaRom-4^{o}, 41), eds. Forsberg, S., Thomasson, B. Stockholm.

Etruscan culture 1962. *Land and people. Archaeological research and studies conducted in San Giovenale and its environs by members of the Swedish Institute in Rome*, ed. Boëthius, A. Malmö.

San Giovenale 1:3. 1967. Hallert, B. *Aerial photogrammetric survey of the San Giovenale area* (ActaRom-4^{o}, 26:1:3). Stockholm.

Spatial Remote Sensing Archaeology and Network Connection Information Theory with Point Resource System

Sun Jianzhong

Shanghai City Development Information and Researcher Center Key lab of Geographic Information Science, China's Ministry of education, Zip200032, sun@public.shucm.sh.cn

Keywords: Remote sensing, archaeology regionPoint Resource (PR)

ABSTRACT

Based on "Integration of remote sensing and ground truth", starts the application remote sensing and the network related information theory, and the widespread start union, is as for the remote sensing based on the archaeology and the cultural heritage in the circulation economic theory, also plays the huge role in remote sensing technology, enables the remote sensing to obtain the unprecedented application surface, has obtained the priceless doubling application value, in the inheritance management angle looked the remote sensing and the network correlation information theory and the practice, is one has the formidable application and market action nature harmonious unite by marriage. This article, by the spatial information main method remote sensing, in addition the spatial information foundation data platform network construction, and shares the widespread practical application scene by spatial and the motion PRS viewpoint which this both soon bring. From it already saw "1+1>2" exactly used. then "1+(1+1>2)>4" continual priceless doubling application value . At the same time, described the Point Resource System and the remote sensing archaeology region, or is the cultural heritage region protection and the management database construction, may enter one to be possible in the predetermined plan network construction, is advantageous for the humanity in archaeology around, all may obtain a more comprehensive grasping and the foreknowledge, as well as the unknown event continually research and the analysis, brings that based on the spatial enormous knowledge support.

1. INTRODUCTION

This paper is proposed when the random point resource event subordinates in the archaeology by a goal, it needs the Spatial Information Basic Data Platform(for short : SIBDP) with remote sensing archaeology data ability characteristic, and the data associating characteristic is described its starting point of the archaeology to simply by the Point Resource(for short : PR) theory. For the purpose of start to the archaeology, that been changed the cultural stratum gradually the archaeology. Human take the PR event within it comes as the entire cultural development archaeology to serve.

1.1 Demanding remote sensing archaeology to SIBDP

"Remote sensing archaeology" in data construction which is forming unceasingly in the platform, therefore, innovates take "the Archaeology Management Engine(AME)" the pattern data and the information resource construction, the application support frame to serve as the archaeology. Based on the request and "the digital city and countryside" the frame, had to strengthened for the information resource the development using basis, from the social discussion remote sensing archaeology, more was related with the ancient times data and the humanities economy dynamic data, all data were needed the routine work to flow ,with it was form throughout in the dynamic management process. Archaeology duty based on above request, confirmation cultural stratum different historical stage place study characteristic, it be constructing essential of compared within the frame.

1.2 Based on the archaeology proposed the information system needs to solve question

What is called the basic data? Basic(Foundation) Data Mean: What is the spatial information, had in addition the attribute data, in addition the daily each work remains down reliably having the scope data. SIBDP is called within Trinity. The impetus basic data platform put in the application being accumulation and construction. When has solved this kind of problem, but based on it also had a carrier concept. (Figure 1)

2. QUESTIONS

2.1Regional spatial information data stream which study

Under present information infrastructure network condition, city passed sector network interconnection intercommunication; Meanwhile under legal instruction, it is becoming and constructing space information data infrastructure. Namely under the network condition the synchronized development data resources enables data so on spatial information and non-space information be flowing to become within that been constructed the harmonious synchronization same into spatial data network..

2.2 Enhancement archaeology plan and overall plan data ability

Namely by archaeology application development, enhancement “Material and Information in Same One” (MIWSO) plan and management, realistic solution in history and under social archaeology data premise associated of original data flowing; It must take the cultural stratum as the basis, that same historical relics union, solves the ancient environment and palaeo-climatology question archaeology in overall plan ability.

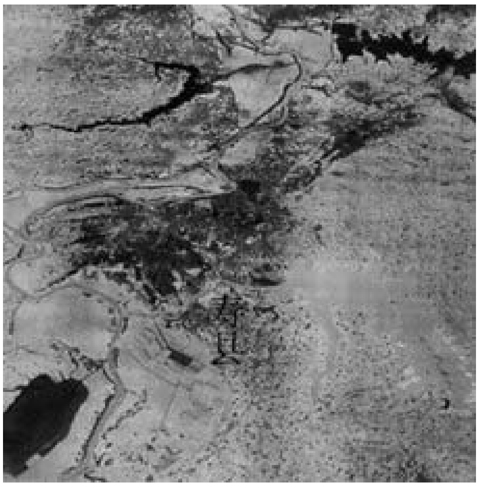


Figure 1： Shou Xian Ancient City be located in (1985, fall) satellite imagery left side of writing (resembled circle non-square in red region)

2.3 The infrastructure and the archaeology information merge into one organic whole

If the archaeology solves of historical data extension and the deletion flaw information for sharing harmonious cooperation with the research question, realizes the archaeology application and the environmental protection synchronization optimization. And in the network of data resources construction, the maintenance becomes the archaeology foundation content and the responsibility. Namely by the information technology and the network method, the promotion archaeology achievement culture and the development, the paleo-climatology, that makes the resources storehouse that been to accumulate into the terrestrial environment protection.

3. ARCHAEOLOGY RESOURCES SCIENCE CONNECTING

Using spatial information grid (SIG), there may take of root platform in the network, might make the contribution for the archaeology information fusion, the hypothesis path ancient times the data stream exchange method and the international archaeology compared to inter it. Because, the region city and countryside, needs to consummate the reliable SIBDP, can adapt the archaeology management, carries on the development data resources to the region archaeology.

3.1Event and may measured platform

Any event has a criterion scope, this is a PR event; But regarding another event connection, is under the identical target sector characteristic another PR event, but the scale may be completely different; For instance an old city goal, first observes generally by PR of the goal event, as if Figure 2 right side , in Ancient City1100$_S$ ago spot , and An Fengtang was named in 1920, subsequently Figure 2 left side of about its old city in characteristic change now.

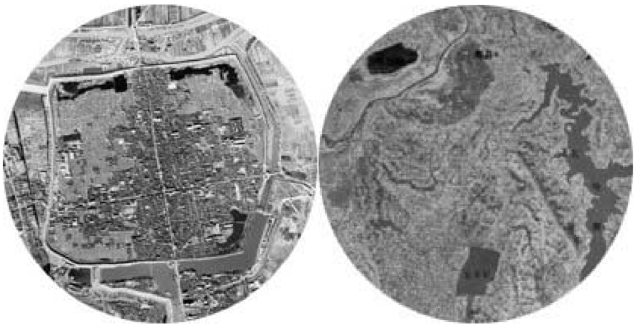


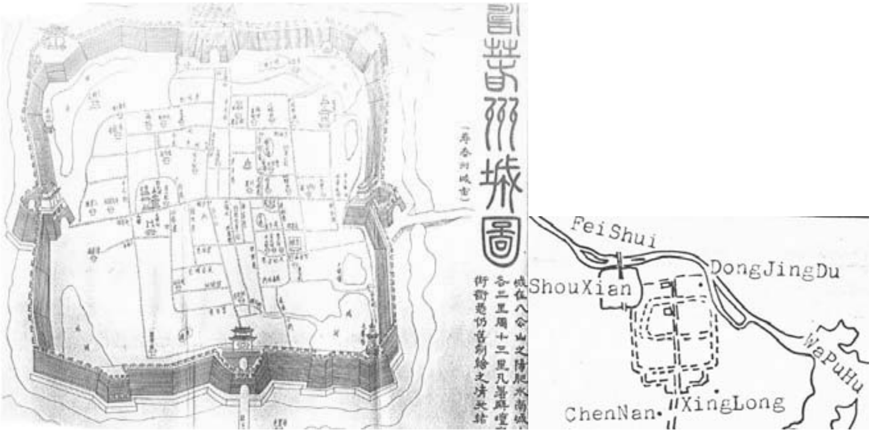
Figure 2： Today the Shou Xian of Song Dynasty repairs the old city position (left：1990s color infrared aerial remote sensing images, right ：north of the middle 1990s Landsat images)

3.2 The archaeology origins Point Resource Theory principle

The archaeology origin just starts regarding the point resource theory application. That, what is PR? When the Earth is born some people, indeed has had primitively "the number" the feeling, that had proven sees the object the same simple number geometry "the structure", therefore can have on the Earth each region ancient's class creation, nearly all equally can have the record, portrays and the scratch behavior expresses the meaning. From this, saw what the spot was? The spot is one may draw comes out, or is in the circle matter information which may record; In the graph theory, the spot may express for is a 1 proportion at least, also may be in an event the analysis content of topology relations number of nodes, again may be a goal the most effective quantity where is the physical threshold PR, chemical change PR. Perhaps is PR which in a human mouth event describes, or is the humanity observes any event in of position PR. The point size dimension has the material PR characteristic with information, it is an extremely important geometry information and matching material world, according to the above also was the information and matching physical world, the archaeology may vividly the description and the recording ancient times and ancient's social being relations. The remote sensing archaeology, pondered based on this PR that, token in the conformity original archaeology data, certainly take the space systems and the archaeology information as hauling, completes the cultural stratum archaeology and with historical relics unification SIBDP .

3.3Example:

PR event "Long-lived Spring City", is the information which is connected all accepts in the China historical cultural city, the city resembles the circle non- square grandly, its style of primitive simplicity, preserves complete, and had 8.33m highest wall which top wide extends 6.66m; This city gate is equipped with the enceinte of city gate (i.e. outside called Luo city), to shape liked the Altar, comply with the water surface streamline form, was equipped with two draining water from 1573 to 1620 to contain; North gate of city is equipped with the water level indication the stone lion, about its elevation 25.5m with same higher to city northwest outside hill is orphaned and isolated to the entire city accomplishes along the topography, not all along topography yet. This city had the years more than 900, experience innumerable inferior earthquakes, safe and sound. First , it towards the northwest approaches hill and nearing river from southeast , second in which has included migration from the older city region which has had the site avoided 2200 ago, and gives a way to processing regarding not well the geological environment and so on, all has stayed behind pleasantly surprised. Including, is apart from its pond south side 30Km far (called Que Bei, renamed with An Fengtang in 1920), its pond dam crest elevation 31m and width 8 until 10m, stored the normal water level elevation 28 to 29m, highest to 29.5m, the water surface reaches $34Km^2$, reservoir perimeter more than 60 Km, originates guiding from the south side thing to the sierra water. In brief, in by the matter which needs to do the archaeology, concentrates information which sees by each kind of information, as well as the collection corresponding PR archaeology data stream; which it integrates the entire cultural stratum to consider that may satisfy and obtains the cultural layer archaeology. Other, included of modern terrain difference, geologic structure provincial characteristics, subsidence belt characteristic interpretation, reservoir water level change and the artificial drainage ditch distribution. The ancient paddy rice planter area under the present arid land yellow soil ground 0.5m place. Differential level elevation sees ancient surface characteristic of runoff water.



Figures 3/4:(3) Clear Guang Xu illustrated handbook. There is old city structure for modern remote sensing it the dynamic changing, has left in behind the indispensable evidence.(4) Chu outline and Song Dynasty repairs it(Shou xian)

4. CONCLUSIONS

The mentality which brings it based on the archaeology in that embarks remote sensing from the archaeology itself rule, describing the PR theory and regarding the archaeology one kind of platform concept simply. That being attempts collection significance which involves some archaeology event, ancient times and the modern environment relation and the future will develop, throughout by this archaeology event from point resource characteristic, developed and taken itself connotation as according to, will solve with other archaeology event and the future environment relations exchange of information and the network service that caused to archaeology will be able to develop and the application from pondered belong to the whole by to human and environment of vestige.

5. REFERENCES

Sun Jian-zhong 1988. *On the environmental significance of the siting of QuiBei South of the Shou County, China*, Balkema, Rotterdam.

Sun Jian-zhong 1990. *Theory and practice of forecasting hazards in remote sensing*, Balkema.

Sun Jian-zhong 1995. Canadian geography and Geomatics industry goal, Remote Sensing Information.

Sun Jian-zhong, Chen Ai-li, Chen Mu 2003. The concept and Application of Point Resource System Object Model, *Journal of Remote Sensing*,7 (6), 440-444.

Gao Fang-qin, Sun Jian-zhong 2004. PRS-Based Information Extraction of Objects in Remote Sensing Image, *Remote Sensing for land & resource*, 3, 18-21.

Field and Laboratory Investigations, An Alternative Tools, To Examine Damage Category Of Monumental Sandstone at Arid Regions, Seti I Temple, Upper Egypt, case study

G. M. E. Kamh[1], R. Azzam[2]

1 Geology Dept., Fac. of Sci., Menoufiya Univ., Egypt, email : g_kamh2000@yahoo.com
2 LIH, RWTH, Aachen Univ., Germany

ABSTRACT

Weathering acts with different intensities and rates on natural and artificial stones based on the dominant environmental conditions at a given area on one hand, limits of geotechnical parameters and durability of a given rock on the other hand.
This paper aims to determine damage category of construction sandstone at arid regions taking Seti I Temple at Qurna "Upper Egypt" that had been built from the Upper Cretaceous sandstone of El-Silsila quarries as a case study; also, it aims to find out if a detailed field investigations can in a semi-quantitative form verify the same damage category that can be quantitatively determined using a detailed laboratory analyses or not. Both of field and laboratory investigations revealed that Seti I Temple has severe to very severe damage category, also it revealed that salt weathering severely affect on the lower courses of this site. In addition, it has been proved that detailed field study and its data processing can to a great extent replace the laboratory investigations that require rock sampling that might be im-permissible at some cases.

1 INTRODUCTION

Weathering processes act worldwide at all climatic conditions and environments attacking sub-aerial natural and artificial building materials (stones, bricks, concrete ….etc). The duration, number of cycles and intensity of weathering processes are controlled by the major and minor changes in the environmental parameters (particularly air temperature and its relative humidity) at a given area as well as materials' physical, mechanical and durability limits.

The Seti I temple is a pharaonic archaeological site located in the Valley of Kings , Egypt. The study area is characterized by annual mean monthly temperature 25.6 °C with maximum mean in Summer 32.7 °C and minimum mean in Winter 17.3 °C. The maximum mean monthly temperature is 42 °C (in July) and its minimum mean is 9.6 °C (in January). The annual mean relative humidity is 37%, the rainfall is limited and scarce with an average 4 – 7 cm/y [15]. So, the study area is considered as an arid to extremely arid at such limits of climatic parameters.

2 METHODOLOGY

To achieve the aims of the current study, Linear Damage index "DI_{lin}" and Progressive Damage index "DI_{prog}" equations listed below

$$\mathbf{DI_{lin} = \{(A*0)+(B*1)+(C*2)+(D*3)+(E*4)+(F*5)\}/100}$$

$$\mathbf{= \{B+(C*2)+(D*3)+(E*4)+(F*5)\}/100}$$

$$\mathbf{DI_{prog} = \sqrt{\ [\{(A*0^2)+(B*1^2)+(C*2^2)+(D*3^2)+(E*4^2)+(F*5^2)\}/100]}}$$

$$\mathbf{= \sqrt{\ [\{B+(C*4)+(D*9)+(E*16)+(F*25)\}/100]}}$$

Where A = area(%) – damage category 0
B = area(%) – damage category 1
C = area(%) – damage category 2
D = area(%) – damage category 3
E = area(%) – damage category 4
F = area(%) – damage category 5 and $\sum_{A}^{F} = 100$

Specimens have been examined through SEM. Geotechnical parameters have been measured for each of un-weathered, slightly weathered and severely weathered sandstone using magneto-structive ultrasonic as a non-destructive technique from the following equations:

$$[(A_o + A_t) / (A_o - A_t)] = X$$

$$(\pi n / Qc) = \{\ln [2 / (1 - X)]\} / (1 + X)$$

$Cp = 2\ Lf / n$ where L is the length of the examined rock sample "cm", the echo-form as well as equipment pattern is clear in figure (3).

Hydrochemical analysis has been conducted for the extracted solutions prepared from the collected rock samples.

3. RESULTS

3.1 Field study

Large area of the temple's floor is severely damp while dry parts of it has thin solid crust of salts that attack the basal courses of this temple. Other parts of this temple that are not severely attacked by salts also have weathering features as obliteration of engraves at heights up to 6m above ground surface.

These field investigations and the computation DI_{lin} and DI_{prog} indicated that Seti I Temple has damage category 5 (very severe damage category).

3.2 Laboratory analyses

3.2.1. Petrographic investigation

Scanning electron microscopic investigation revealed that the construction rock is medium size arenite sandstone, consists of euhedral quartz grains with silica overgrowth. Pitting and deformation of silica overgrowth can be traced and tiny size spherical shaped iron oxide particles that partially fill rock's pores, kaolinite can easily be traced. At some parts, halite has been detected (using SEM supported with EDX) covering most of the rock components.

3.2.2 Hydrochemical results

The slightly weathered sandstone has an electrical conductivity (E.C.) ranging from 9.6 to 12.8 mmhos/cm and total dissolved salts (T.D.S.) ranging from 18,904 to 23,735 ppm; the moderately weathered sandstone has an electrical conductivity 16.3 mmhos/cm and total dissolved salts 21,308 ppm; and that of the severely weathered sandstone has E.C. ranging from 21.2 to 31.2 mmhos/cm and T.D.S. from 94,156 to 106,225 ppm. The dominant hypothetical dissolved salts are mostly chlorides (particularly NaCl salt) followed by sulphate salts (particularly Na_2SO_4 and low percentage of $CaSO_4$).

4. DISCUSSION AND CONCLUSION

The damage category at some parts of Seti I Temple reaches up to severe and very severe damage, other parts are down to slight and very slight damage category. The overall damage category for this temple based on field investigation considering all weathering forms is found to be very severe damage category.

The laboratory investigations revealed indicated that salts at and on stone surface deform rock's texture on salt crystallization particularly for chloride salts.

Field and laboratory investigations can alternate each other in quantifying rock damage category and this is fruitful for the highly ranked archaeological sites.

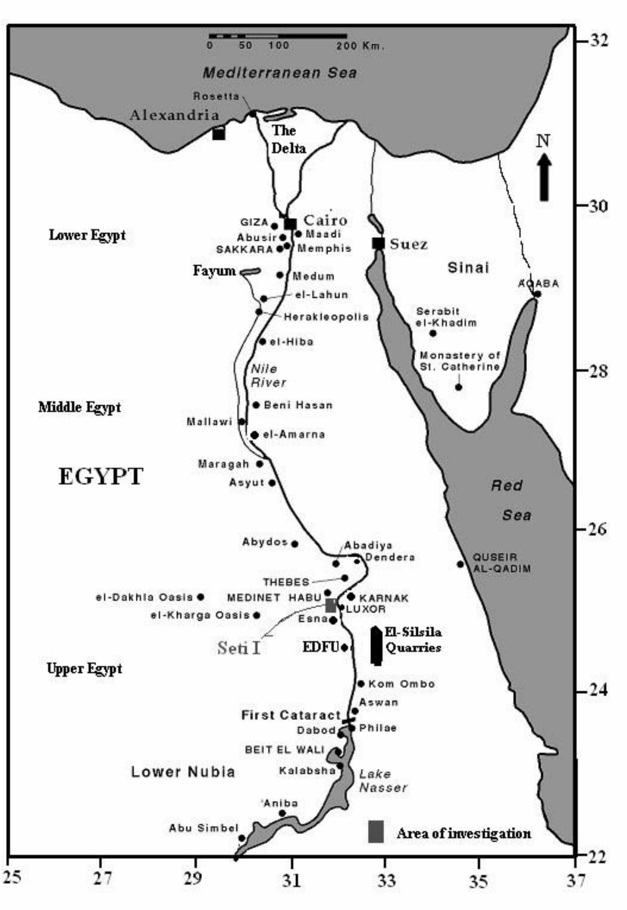


Fig. 1. Map of Egypt with location of investigated area

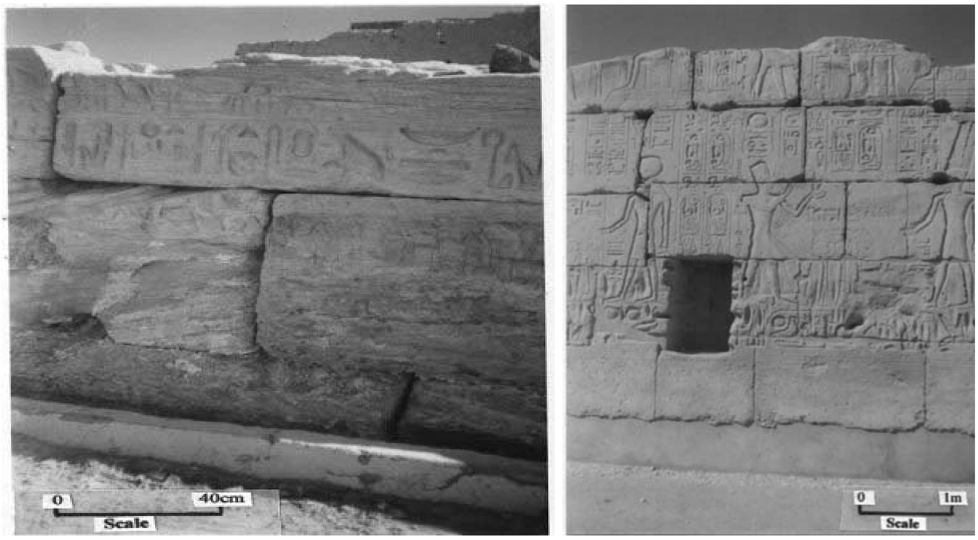


Fig. 2. (left) Severely weathered sandstone basal courses at West facing wall side of the first pylon, Seti I Temple; (right) Slight to moderately weathered west facing wall side of the Seti I Temple, parts of investigation number 8 and 9.

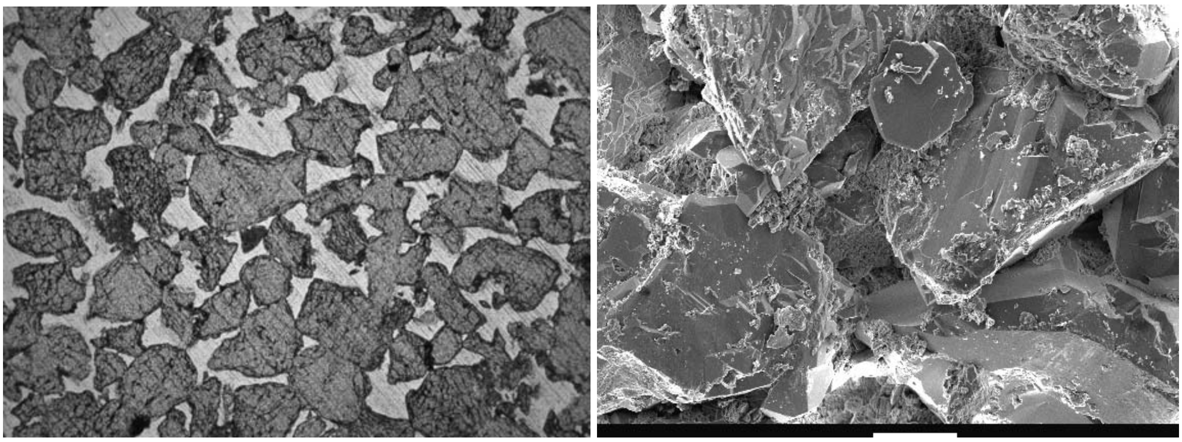


Figure 3. (left) Thin section photo-micrograph presenting rock texture of medium size sandstone of Seti I Temple; (right) Scanning electron photo-micrograph presenting micro-fragmentation of silica overgrowth

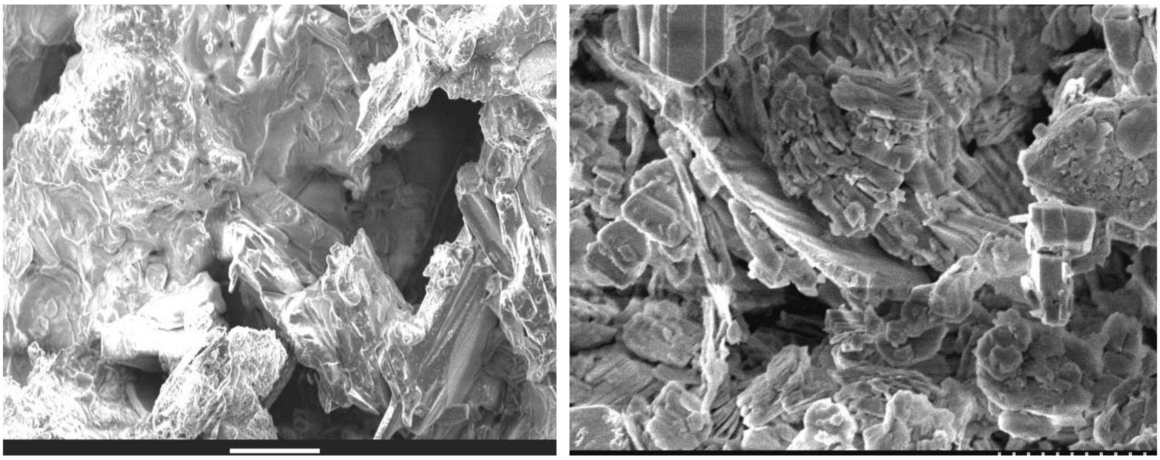


Figure 4. (left) Scanning electron photo-micrograph presenting Halite coating most of the sandstone components, Seti I Temple; (right) Scanning electron photo-micrograph presenting deformation in Kaolinite and feldspar texture by salt deformation in Kaolinite and feldspar texture by salt.

6

3D visualization and Virtual reconstruction of landscape and sites

From remote sensing to 3D modelling and virtual reconstructions of the Iraqi archaeological sites: the case of Hatra

M. Cultraro[1], F. Gabellone[2], G. Scardozzi[2]

1 CNR- IBAM. *Italian National Research Council - Institute for Archaeological and Monumental Heritage, Via Biblioteca 11, c/o Palazzo Ingrassia, 95124, Catania (Italy); m.cultraro@ibam.cnr.it*

2 CNR- IBAM. *Italian National Research Council - Institute for Archaeological and Monumental Heritage, Strada per Monteroni, Campus Universitario, 73100, Lecce (Italy); f.gabelone@ibam.cnr.it, g.scardozzi@ibam.cnr.it*

Keywords: Archaeology, 3D Modelling, Virtual Reconstruction, High Resolution Images, Iraq

ABSTRACT: The study was developed in the *Iraq Virtual Museum* Project, that entails the construction of a Virtual Museum of the main archaeological treasures of the ancient civilisations that flourished in the territory of modern-day Iraq. The contribution of the Institute for Archaeological and Monumental Heritage of the Italian National Council of Researches (CNR - IBAM) in the project derives from the need to contextualize objects showed in the Virtual Museum, linking them to their sites of provenance; this result was achieved by recourse to satellite remote sensing and to image-based technologies. The archaeological sites analysed in the project were documented by cataloguing the most significant monuments, in terms of historical and topographical development. High resolution satellite images made it possible to observe and document the archaeological areas as they are today, and to acquire new knowledge about monuments, urban layouts and historical landscapes (archaeological and paleo-environmental data). A number of sites, monuments and objects that are more representative have been reconstructed by means of image-based modelling and rendering. For some sites, like the ancient city of Hatra, the exemplificative case study that we present here, the virtual reconstruction is partially based on satellite multitemporal images. The results of this experience show the potential of the integrated use of data from archaeological excavations, satellite remote sensing data and image-based technologies (photo-modelling and digital photogrammetry) as an effective methodology for study, documentation, analysis, reconstruction and presentation of ancient sites.

1 INTRODUCTION

The experience presented in this paper has been gained in the context of the *Iraq Virtual Museum* (*IVM*) Project, promoted by the Italian Ministry of Foreign Affairs and under the scientific activity of the National Council of Researches (CNR, *Consiglio Nazionale delle Ricerche*). The main goal of the project, under the scientific direction of Dr. Massimo Cultraro (CNR-IBAM), is the paragmatical construction of a Virtual platform, using the most recent advanced image-based 3D modelling (photo-modelling and digital photogrammetry), in order to lead a large public to enjoy the main archaeological treasures of the ancient Mesopotamia, after the destruction of the Baghdad Museum in 2003. The contribution of the Institute for Archaeological and Monumental Heritage (CNR- IBAM) in the *IVM* Project is strictly related to the reconstruction of some exhibition halls of the Archaeological Museum of Baghdad. In this context we have attempted to employ Virtual Reality Technology and an extensive use of multimedia, as well as communication technologies.

The Virtual Museum of Baghdad is not a real reproduction of the first archaeological collection before the definite looting and destruction. The museum represents the most creative part of an imaginary collection, which includes a selective series of artefacts transposed in digital form, each of them is related to the archaeological, as well as cultural, framework of finding. In this latter field the team operating in the CNR-IBAM has employed the most advanced technologies in studying monuments and ancient sites. It is an integrated use between traditional data coming the archaeological excavations, and remote sensing data. The investigation of the most important architectural monuments in each selected sites of Ancient Mesopotamia provides an excellent documentation in order to reconstruct the main features of an archaeological site. Moreover, the use of high resolution satellite images makes it possible to observe and to document the real conditions of the ancient sites, both as a substitutive tool for a real visit that is currently not realisable. The result of this experience, that we have firstly applied in the reconstruction of Dur-Sharrukin and of the palace of Sargon II (Cultraro, Gabellone, Scardozzi 2007), shows the potential of the integrated use of different data and technologies. The aim of this paper is to apply the same methodologies and digital technologies in the case of Hatra. The excellent preservation of the city and the total absence of a reuse of the area give us the opportunity to employ recent scientific methodologies in order to reconstruct the topographical and architectural context of this important Parthian town.

2 HATRA, THE CITY AND ITS BUILDINGS

The city was situated in West Jazirah (now North Iraq) between the Tigris and Euphrates, ideally located into a strategic position to control the main ways along both rivers (Venco Ricciardi 2000 and 2005, with bibliography). Hatra had the most important period between the 1st and 3rd century AD under the kingdom of Parthians until the destruction by the Sasanian emperor Shapur I in 241 AD. Roman army repeatedly attempted to conquer this strategic Parthian outpost (under Trajan in 116 AD and Septimius Severus in 199 AD), but the town always remained an independent centre. Hatra, despite is located in the semi-arid steppe, which becomes greenery in the spring, was protected from an impressive fortification system done by a stone basement and a mudbrick superstructure. The outside line (about 3 km in diameter) was built probably after the Trajan siege and served to protected the cultivated areas around the city. The inner defensive system, always constructed from mudbricks and stones, was fortified by 163 impressive towers and 4 main gates. The urban area was round planned and was crossed by a number of streets that starting from the four main gates converged towards the Great Temple in the middle of the city. Moreover, a series of minor roads intersected with the four main routes forming a circular grid.

Protected by a such impressive double fortified system, Hatra encompassed at its centre many public buildings and cult places. The fulcrum of the city was the large rectangular area (437 x 322 m), which includes a concentration of important buildings, among them the Great Temple dedicated to *Shamash*, the Sun-God. The building, which in its current form dates to the 2nd century AD, is made up of two huge *iwans* flanked by various minor structures, that were added later. The other 14 minor religious buildings, excavated by the Iraqi archaeologists, show differences of plan and architecture details with the Great Temple, reconnecting with the traditional Mesopotamian religious architecture. Finally, in the perspective of the use of high resolution satellite images, of particular interest is the wide area out of the city, where is possible to identify a road system and bridges connecting Hatra with the nearby cities, particularly with Ashur. The area where the city was build, in fact, was crossed by a large grid of trade roads from Syria to Mesopotamia, connecting Seleucia and other important city of Upper Mesopotamia.

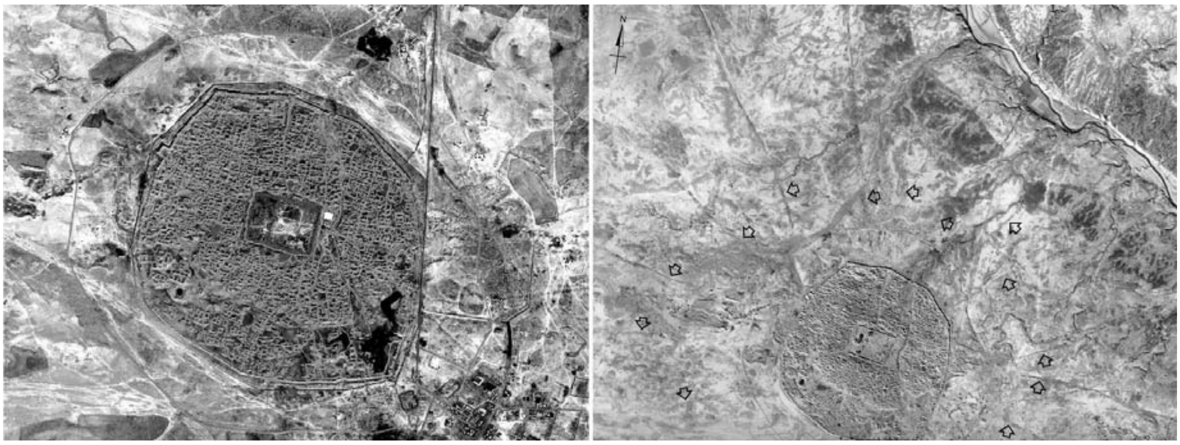
3 PROCESSING AND ANALYSIS OF REMOTE SENSING DATA

For the reconstructive study of Hatra, multi-temporal remote sensing images had provided new data about its topographical layout, monuments and ancient viability in the city and in the surrounding territory. First of all, recent high resolutions images of civil satellites were acquired: particularly, an Ikonos-2 image taken in 2nd of September 2002 (Geo-Ortho Kit Bundle, with pixels re-sampled to 1 and 4 m respectively in panchromatic and multispectral mode), and two QuickBird-2 images taken in 18th of October and in 6th of March 2006 (Standard Ortho-ready products, with pixels re-sampled to 0.60 and 2.40 m). These images were used to document the modern situation of the ancient site and for monitoring the situations before and after second Gulf War; they give a general view of the entire city and its environs and allow to examine in detail all the archaeological evidences visible on the surface.

The processing and analysis of the panchromatic and multispectral images made it possible also to acquire new data about monuments, urban layout and historical landscape. In fact, they show all the structures still preserved and some of those that are partially buried or completely buried, and also a lot of archaeological elements that are hardly perceivable on the ground; for example, they clearly reveal many mounds of collapsed house-walls and even a lot of complete streets around the house blocks. All these elements were added to the archaeological map of the city; in fact, the satellite images were orthorectified on a DEM based on SRTM data, and the vectorialization of all ancient remains and traces allowed the integration and the update of the archaeological map of Hatra, with new data about ancient layout, monuments and roads (Fig. 1). So, these images can also be used for the documentation of the archaeological remains, clarifying topographical situations and even allowing fairly punctual measurements. Moreover, the new updated archaeological map was used as base plan for the 3D reconstruction of the city and its monuments.

In the satellite images is clearly visible all the circular plan of Hatra, with the external fortification about 9 km long (that closed an area of 620 hectares), with zig-zag salients, and the inner city wall about 6,4 km long (that surrounded a surface of 300 hectares). In the centre of the city is the rectangular sacred enclosure, that was divided in two sectors: the eastern, bigger (approx. 9,5 hectares) and without relevant buildings, and the western, smaller (approx. 4,5 hectares), where are concentrated the sacred edifices like the Great Temple. The symmetrical enclosure contrasts with the layout of the surrounding houses blocks and streets: some of these are fairly straight but a regular planning was not applied to them. In this area are visible some excavated structures, like the North Palace near the North Gate, the Edifice A, and the monumental tombs of the necropolises; is also possible to distinguish the basin for water in the south-west quarter of the city.

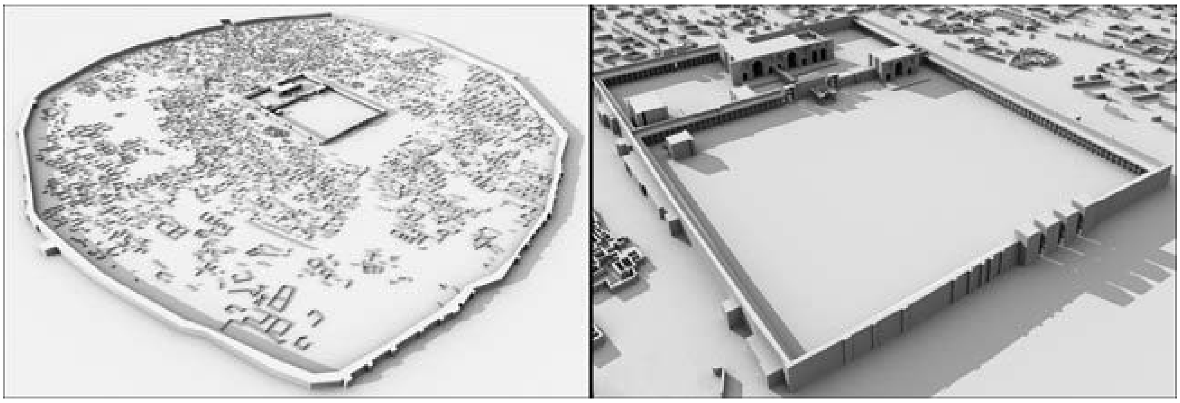
The recent satellite images were also integrated with older remote sensing data, particularly with an high resolution space photo taken by USA reconnaissance satellite Corona KH-4B during the mission n° 1102 (11th of December 1967; ground resolution of about 1.85 m) and some oblique and vertical air-photos taken in 1920s and in 1930s (about them see Bradford 1957: 71-75, and fig. 24). These images are very interesting for the documentation of the situation before the first Gulf War and also before the start of archaeological excavations and restorations; they show the remains of Hatra even before the building of modern structures in the area of the south-eastern corner of the external city wall, that in the air and satellite photos appear more preserved that today. These images show more evident than recent satellite images the traces of many ancient routes that radiating from Hatra ("hollow ways"), that often remained in use for millennia; a study based on the integration of Corona satellite photos taken in August 1968 and in December 1969, and the Tabula Peutingeriana had evidenced the role of the city as an important meeting point of trade routes crossing the eastern Jazira, principally with a NW-SE direction, connecting the Arsacid capital Ctesiphon and lowland Mesopotamia in general with Armenia and the eastern border of the Roman Empire (Altawell, Hauser 2004). Particularly, the Corona KH-4B photo of 1967 (Fig. 2) shows a lot of traces of short distance roads (connecting the city to neighbouring sites and little villages) and long distance routes, like that in ESE direction that connected Hatra to Ashur. All the elements that appear in these air and satellite photos were also georeferenced in the new archaeological map of Hatra.



Figures 1-2. Orthorectified QuickBird-2 image with vectorialization of the archaeological evidences (in pink); plans of some monuments are also georeferenced on the image (in red). Corona KH-4B photo of 1967: the shadows indicate traces of ancient roads radiating from Hatra in west, north and east direction.

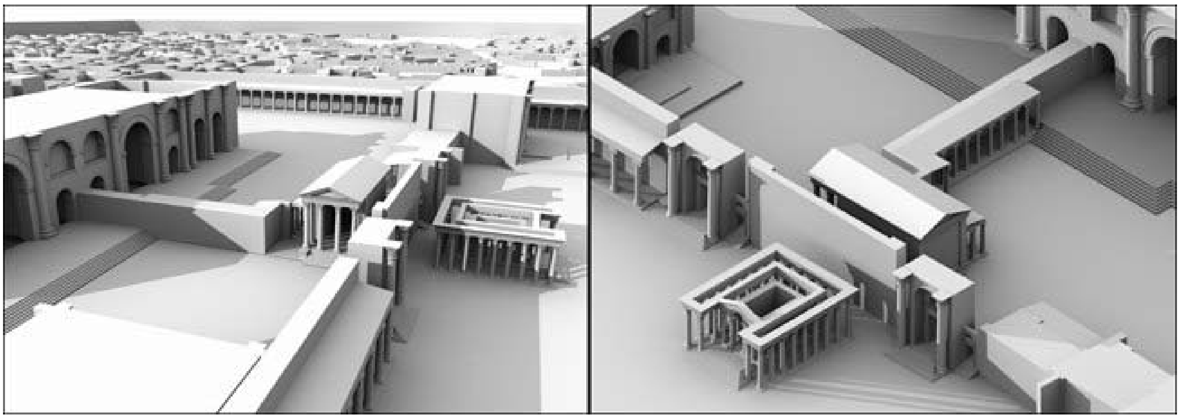
4 THREE-DIMENSIONAL RESTITUTION: PRELIMINARY RESULTS

Studying a monument with a view to its reconstruction involves combining historic and humanistic knowledge with the use of modern information technologies, not just to understand and interpret ancient building complexes, but also – and especially – to transmit the knowledge acquired to a broad and heterogeneous public via appropriate media at varying levels of interest and understanding. We believe that this is an exciting time for archaeology, which is increasingly in the public spotlight, thanks (among other things) to the communicative power of the tools that are now available. These tools make it possible to recreate not only shapes and materials, but also to capture the atmosphere of daily life in ancient times. Evidence for this may be seen in the enormous growth on the web of virtual and thematic museums, of virtual collections and galleries, all designed to promote knowledge of archaeological and monumental heritage items by means of these new technologies. The reconstructive study of the city of Hatra (still in progress) is clearly a highly challenging and complex task, and it will be some time yet before the studies and data processing reach a point where they can provide a plausible and complete visual representation of the urban layout. The city was the crossroads of important caravan routes, but it was also the crossroads of a number of religions – Semitic, Greek and Mesopotamian. The traces of the ancient city, which are still partly visible *in situ*, tell the story of this blend of cultures and styles, particularly admirable in terms of the formal characteristics of the temples. Here, Hellenistic and Roman architectural influences are superimposed on decorative elements of oriental origin, giving rise to a style of architecture that is truly exceptional, and has quite rightly been included in the UNESCO list of world heritage sites.



Figures 3-4. 3D models of the city and the internal walls, and of the sacred enclosure.

The 3D restitution that we propose here represents merely the starting point for the formulation of hypotheses, which will obviously require further studies and excavations. However, it has been possible to start tracing the layout of the city using a new methodological approach that combines humanistic and technical-scientific knowledge. The 3D models were obtained by comparing the results of the analysis and vectorialization of satellite images, the information from past excavations, and the evidence from the site in its current state. The images shown here highlight the presence of densely-packed residential buildings across much of the city. This phenomenon, knowledge of which was previously rather limited, is observed around the great monumental buildings in the central area. The satellite images also show that the streets of the city were not arranged in a regular grid and that the circuit of defensive walls included towers at regular intervals. These initial results will be of help to the reconstructive study as it proceeds with the recognition of individual dwellings and the city's main gates, helping to provide a clearer picture of the arrangement of the road network both inside and outside the city.



Figures 5-6. Particulars of the 3D model of the sacred enclosure.

5 ACKNOWLEDGEMENTS

Special thanks go to the team of CNR-IBAM that have worked in the reconstructive study of Hatra, particularly in the processing, orthorectification and vectorialization of satellite images, and in the 3D modelling: Doctors Giacomo Di Giacomo, Fabrizio Ghio, Massimo Limoncelli and Giuseppe Pellino.

6 REFERENCES

Altaweel, M.R., Hauser, S.R. 2004. Trade routes to Hatra according to evidence from ancient sources and modern satellite imagery, *Baghdader Mitteilungen*, 35: 59-86.
Bradford, J. 1957. *Ancient Landscapes. Studies in Field Archaeology*, London.
Cultraro, M., Gabellone, F., Scardozzi, G. 2007. Integrated Methodologies and Technologies for the reconstructive study of Dur-Sharrukin (Iraq), *XXI CIPA Symposium (1-6 October 2007, Athens)*, Athens, 253-258.
Venco Ricciardi, R. 2000. Hatra. Presentazione del sito, *Topoi* 10: 87-110.
Venco Ricciardi, R. 2005. Hatra, *Enciclopedia archeologica*, *Asia*, Roma, 309-311.

Multi-scale geometry acquisition and visualization: issues and techniques

M. Callieri, M. Dellepiane, F. Ganovelli, R. Scopigno

Visual Computing Lab, ISTI-CNR, Via G. Moruzzi 1, Pisa, name.surname@isti.cnr.it

Keywords: data acquisition, 3D scanning, interactive visualization

ABSTRACT

Cultural heritage has always been a privileged field for the application of new techniques for geometry acquisition and visualization. The improvement of hardware devices, and the outstanding advancement in algorithms resulted in the possibility to manage and interactively visualize impressive amounts of data. Entire geographic areas can be handled, and information at different level of detail has to be managed more frequently than in the past. Useful data can be provided from very different sources (time-of-flight and triangulation scanners, modeled meshes, satellite data, height maps, cadastral maps, drawings, etc). Several issues arise in the context of the integration of such heterogeneous geometric data. It is possible to identify three main problems: the interpretation and codification of input data, the integration/merge of geometry available at different levels of detail (e.g. acquired with radically different sampling resolution) and the interactive visualization of heterogeneous databases. In this paper we analyze these issues and present some solutions which we had the opportunity to investigate in the context of different projects.

1 INTRODUCTION

The problem of geometric data presenting severe differences in scale is often encountered while working with three-dimensional digital models, especially considering that in the last few years the growth of hardware devices capacity and algorithms efficiency have led to impressive results in acquisition and visualization of dense geometric datasets.

In order to better explain what we mean by *different scale*, a possible (very rough and incomplete) classification of three-dimensional geometries may be given as follows:

- Human scale, from a pen to a car, measurable in centimeters
- Building scale, from a train to a large building, measurable in meters
- City scale, from a city block to a metropolis, measurable in hundreds of meters
- Terrain scale, from a park to a planet, measured in kilometers

While it is true that, in a digital model, the scale is not really important, since it is always possible to display the entire extent of an object in the screen, it is also true that is really hard to be able to display objects that span two or more orders of magnitude in size. How is it possible to grant the user a good perception of the different scales appearing in the scene while keeping a coherent interface and visualization system?

Besides the visualization problems, also the sheer loading and visualization of the models can be a non-trivial task, since objects at different scale are often stored in different (sometimes proprietary) formats and can have peculiar geometric features (unstructured vs. structured, large number of small polygons vs. small number of large polygons, triangulated vs. implicit surfaces).

All these difficulties can also be explained by the fact that the technologies for creation, management and visualization of these kinds of data evolved concurrently: nowadays each different scale has its own software manipulation and scanning hardware device. Moreover, due to the different aim of the scale models, also the visualization techniques can vary between them.

This separation was also affected by the fact that until recent times, the available computational power did not allow to consider the possible integration of such differentiated data.

For all these reasons, it is easy to understand how difficult it is to try to integrate data with different scales. Nevertheless, finding a way to integrate multi-scale data in a single application can bring new level of understanding of the scene, since each object can be viewed in its correct context (see section 2.1 and 2.2).

Integration of different scales is not only useful for visualization purpose, but also from the information that can be derived from one scale to another, thus to improve our capacity to build a more complete and better representation of the scene (see section 2.3)

In the following section, we will present three different projects in which the multi-scale nature of the geometry data is handled to improve final results by best exploiting the provided information.

2 THREE EXAMPLES OF MULTI-SCALE GEOMETRY ACQUISITION AND VISUALIZATION

2.1 Geographical visualization

In a recent project related to tourism promotion, the goal was to build a web-based application to visualize geographical information and urban areas. The user should have been able to see all the buildings and the surrounding terrain, and have some selected sites reproduced with higher detail.

The viewer was based on a commercial product, Unity3D (http://unity3d.com/), which has a good scene graph management for polygonal meshes, animation and interaction instruments, and a web plug-in architecture. Unfortunately, it does not natively read multiple data formats.

The real issue was, in fact, to manage and integrate the data coming from the different sources, and transform them in polygonal meshes which can be read by Unity. The data was mainly available through the regional geographical office, and came in a GIS-oriented format, which is not really usable for three-dimensional visualization.

The terrain was available as a height map, each grid cell with a side of 10 meters, divided in various “sheets” (following the old military cartography organization). A specific tool was designed to be able to extract each desired patch from multiple elevation data sheets, to convert it into an optimized triangular mesh. The mesh was then divided in chunks (to avoid big meshes) and imported flawlessly into Unity3D. For some of the smaller datasets, instead of using the raw geometry format, we opted to use the Unity built-in terrain, which has better performance because it uses an adaptive LOD representation.

Generic building data have been obtained from local administrations, encoded as cadastrial data using the ShapeFile format, with the building ground shape stored as a polyline plus a height value. Using these data, it was easy to build sketchy three-dimensional meshes by just extruding the base polyline, and triangulating a rooftop. Generating a single model with the whole cadastre building was not the best choice, since the visualization engine performs a per-object culling and, given the extent of the complete city area, the entire model had always to be processed. Generating a single object for each building was not viable as well, because it would have made the scene hard to manipulate (even simple villages can have more than one thousand building shapes). We opted for an intermediate solution of grouping buildings in clusters to obtain better visualization performances. Unfortunately, the buildings inside the shapefiles were not arranged by position, and we had to write ad hoc procedures, based on the data extent and proximity, to determine a location-driven partition of the building set.

Moreover, particularly interesting sites had been modeled with a photo-based reconstruction tool (Google SketchUp). Though these models had a polygon count which is four-five times larger than the cadastrial data, they were still manageable by the Unity engine.

The result was a viewer that integrated three of the scale levels aforementioned; in this case most of the work consisted in format translation and data assembly.

2.2 Multi-resolution Visualization of Large Urban Models

In the context of a Crisis Simulation System, which was the goal of the EU project (EU PASR-2004 “CRIMSON”) we developed a system for interactive visualization of large urban models based on a novel data structure called BlockMap.

The key idea of the BlockMap (Cignoni *et al.*, 2007) is that any small portion of a city can be compactly represented in a raster mode as a sort *check-board* whose tiles are lifted to mimic the shape of the buildings. The advantage of this representation is twofold: it captures the large scale features of a city, i.e. the silhouette of its buildings as seen from a distance, and it can be very easily arranged as a special type of texture, to be efficiently rendered by harnessing current graphics hardware capabilities (GPU-based ray casting).

Together with the shape of the buildings, the BlockMap also encodes their color by a simple parameterization of the roofs and sides. BlockMaps are used in place of the original data only when their projection on the screen is so small that the difference with original model is unnoticeable. In other terms, a BlockMap is an omni-directional impostor and, as any impostor, it replicates the appearance of the original data when *far away* from the observer.

Given a textured geometry of a city, which can be obtained from cadastral maps as well as 3D scanning, a hierarchy of BlockMaps is built by recursively subdividing the region occupied by the city to form a quad-tree, and building a BlockMap for each node. Such hierarchy is used at rendering time in a multiresolution fashion, by choosing the nodes to visualize on the base of their approximation.

2.3 The acquisition of the Portalada de Ripoll

The aim of the Portalada project (Besora *et al*., 2008) was the acquisition of the Portalada, the stone entrance (11x7 meters) of the Benedictinian Monastery of Ripoll, in Catalunya. The Portalada is defined as the "Stone Bible ": every single section tells a story, sacred and profane mix continuously throughout its surface. For this reason, the acquisition of the portal needed a particular care in the preservation of detail. Hence, triangulation laser scanning technique was chosen to acquire the whole geometry of the portal, with sub-millimetric precision.

Nevertheless, a second time-of-flight acquisition was perfomed as well: this was due to three main reasons:

- The time-of-flight scanned model was used as a reference for the alignment of the range maps obtained with triangulation scanner: this prevented possible issues related to global alignment and slight deformations in the final model.
- The different point of view and more consistent coverage of a time-of-flight scanning could provide more information, and cover parts which could not be acquired by the triangulation scanning.
- A low resolution scanning of the area around Portalada was a good data set to visually describe the current position of the monument.

The final result of the project (a 170 Million faces 3D model, obtained from more than two thousand range maps) was a very interesting example of how the exchange of information between two models at different scale (in this case, millimeters vs. centimeters) can lead to a simplification in the processing of data, and to an improvement in the final result.

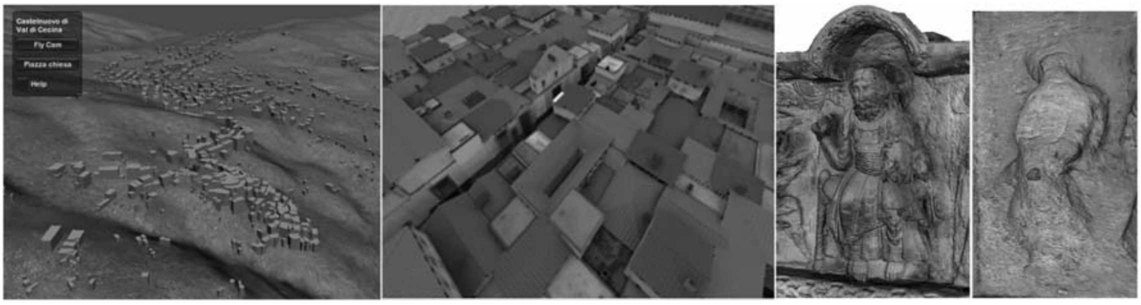


Figure 1. Left: a screenshot of the Geographic visualization system (Section 2.1). Center: the Pompei recostruction visualized using BlockMaps (Section 2.2). Right: Details of the final Portalada model (Section 2.3)

3 REFERENCES

Besora, I., Brunet, P., Callieri, M., Chica, A., Corsini, M., Dellepiane, M., Morales, D., Moyés, J., Ranzuglia, G., Scopigno, R. 2008. Portalada: A Virtual Reconstruction of the Entrance of the Ripoll Monastery. *3DPVT08: Fourth International Symposium on 3D Data Processing, Visualization and Transmission*. Atlanta, USA.

Cignoni, p., Di Benedetto, M, Ganovelli, F., Gobbetti, E., Marton, F., Scopino,R., Casted BlockMaps for Large Urban Models Streaming and Visualization, *Computer Graphics Forum*, Volume 26, Number 3 - Sept. 2007

Virtual Rome project: a web-based VR application on the archaeological landscape of Rome

S. Pescarin[1], L. Calori[2], M. Forte[3]

1 VHLab, CNR ITABC, Rome, Italy, sofia.pescarin@itabc.cnr.it
2 Cineca, Bologna, Italy, l.calori@cineca.it
3 University of California, Merced, USA, mforte@umerced.edu

Keywords: Landscape, Virtual Heritage, archaeology, Web-application

ABSTRACT.

The Virtual Heritage Lab of ITABC CNR in cooperation with CINECA Supercomputing Lab and the University of California is developing a new framework, based on an open-source approach, whose goal is to enable the reconstruction of ancient landscapes through the web and a 3d real-time environment (cooperative VR environment). The framework, although still under development, has been tested in an innovative project, the “Virtual Rome Project”, that regards the reconstruction of the archaeological landscape of the territory of Rome and its publication over the web, through a 3d plug-in called OSG4WEB, originally developed by the team. With a intra-site and inter-sites approach, it is possible to interactively navigate inside the landscape (figure 1), and also inside its monuments, such in the case of the Villa of Livia at Prima Porta (figure 2).

Thanks to this project, financed by Seat Yellow Pages and the Roman Chamber of Commerce, with the cooperation of Roman Superintendence, different methodologies (remote sensing, GIS, 3d modeling, etc) and data were integrated at different levels of detail and scale, in order to obtain a reconstruction of the archaeological landscape and of the potential Roman landscape (2nd cent. AD) in its complexity. The reconstruction was achieved through the application of an explicit scientific method, integrating published and original archaeological and paleo-environmental data. The VR webGIS application is completely based on geospecific data (DTM, geoimages, vector layers) and high-resolution 3d models (acquired and processed with different technique such as scanner laser and photo modeling). Specific algorithms were used in order to create paged and scalable models (for terrains and 3d models), useful for an efficient on line interaction. Functionalities such as switching capabilities, view points, “tooltips”, etc. have been also developed. Future developments within the framework include the development of a fully cooperative application, that will enable distant researchers to work together at landscape reconstruction, directly inside the 3d environment.

1. INTRODUCTION: THE PROJECT

Virtual Rome project, coordinated and directed by CNR ITABC, aims at studying, interpreting and reconstructing the archaeological landscape of ancient Rome and at enabling its distributed and interactive visualisation through a web-based Virtual Reality application (VR webGIS), based on Open Source libraries and on GIS data and 3d models. A plug-in was developed for this purpose; it enables a fully interactive 3d experience in ancient spaces, embedded in most diffuse browsers.

The project was founded by Seat Yellow Pages and the Roman Chamber of Commerce. Its final goal is the evolution of the VR application into a 3d interactive editable on line laboratory on ancient landscape, interactively updatable even with different projects and models, developed by other institutions/partners.

Thanks to a research agreement signed among CNR ITABC of Rome, CINECA Supercomputing Center of Bologna and the University of California-Merced, the project involve the team in a mush wider perspective, from an archaeological, communicative and IT point of view. In fact the project is carried on in order to comprise, along with the 3d reconstruction of the landscape available over the web through the plug-in, as further development, a web-based 3d cooperative interactive environment. While the first goal is already achieved (Virtual Rome VR webGIS), the second is in progress (3d web-Lab).

Virtual Rome VR application achieved the following results: development of the software OSG4WEB plug-in for Internet Explorer and Mozilla Firefox; development of 2d and 3d contents regarding archaeology, architecture and environment of Rome in 21st and 2nd centuries BC; development of several utilities for 3d contents publication over the web, as paged 3d terrains, vegetation, optimized 3d models, multimedia hyperlinks; 3d Internet site on Roman landscape.

2. THE LANDSCAPE

For Virtual Rome project the main goal was the reconstruction of its archaeological and ancient landscape, during Roman times (2nd cent. AD), accessible in 3d, interactively and on line through a VR webGIS system.

For the reconstruction of the archaeological and ancient landscape a scientific explicit theoretic approach was followed, that was reached through the use of GIS tools and applications aimed at the reconstruction of Virtual Ecosystems.

We developed two main overlapping georeferenced dataset, at a wider scale: the first regards the actual archaeological landscape (from 100 mt up to 20 cm resolution) and the second the ancient Roman landscape (100 mt up to 1 mt resolution). Each dataset is composed by a Digital Terrain Model (DTM), by a mosaic of georeferenced images (satellite and aerial images, in the first case, and artificial photorealistic digital images, in the second case), by a series of paged 3d models, by vegetation libraries (mainly quad) and vector thematic layers. 3D models, vegetation and multimedia contents are stored in a MySQL database, connected to back-end and front-end parts.

Three areas were also developed at a better resolution (1 mt – 10 cm resolution): ancient via Flaminia, in the northern part of Rome, via Appia archaeological Park, south and Imperial for a, in the centre of the city.

The entire application is developed using paging techniques, therefore resolution and scale are automatically uploaded on the 3d scene when needed. It is though also to be further updated, adding more or different contents.

In order to obtain landscapes reconstruction different geospatial (raster and vector) data were used and integrated. In particular we could use a large archive of aerial images, with a resolution of 20 cm, provided by Nuova Telespazio, thanks to Seat Yellow Pages.

Moreover, in order to work on the archaeological and interpreted landscape, we studied and acquired different archaeological, topographic and architectonic data, referred to the territory and the three areas. Thanks to several cooperation and research agreements, we acquired and use the archaeological map of Rome (Carta dell'Agro), a vegetation index map, a litho-stratigraphic map and the map of soils of Rome. In order to create a reliable scientific georeferenced base, we set up several archaeological campaigns and surveys with DGPS, Laser Total Station and Laser Scanner in order to verify correctness and completeness of available data. After this phase we noticed that some information needed to be changed, modified and even added. The original sources, in fact, were lacking of precious information or were wrong or with not enough resolution.

From a chronological point of view, we managed data referred to two main periods: the 21st and the 2nd centuries AD. Following an ecological approach, for each of this period was developed a model regarding, respectively, the archaeological landscape (contemporary landscape in its diachronicity) and the ancient potential landscape (the ancient interpreted reconstructed landscape).

Three-dimensional models were integrated in the landscape with two different techniques: general typological models as 3d reference (resolution 10 mt), and detailed reconstructed models (resolution 1 mt - 10 cm). In this way the user can have a clearer idea of the use of the territory, through the analysis of the position of the different sites, and also see the detailed models in their context and relational interconnections. Some important sites have been completely reconstructed, such as Milvio Bridge, the funerary site of Malborghetto, the Villa of Livia – emperor Augustus wife - at Prima Porta, Malborghetto Constantine Arch, Caffarella Park with its monuments such as the Nympheum of Egeria and Saint Urbanus church, or some monuments along the via Appia. Some of these monuments are actually interactively visible even in their interiors.

Different modelling techniques were adopted. Although the key monuments were acquired, at a very resoluted scale, with Scanner Laser technology, we found that photo-modelling technique was the best solution to document archaeological sites and to obtain reliable, precise 3d models, but also “light” and therefore useful for an Internet use, at the same time. About the typological 3d models we added almost 1500 monuments (figure 1).

3. PROBLEMS ENCOUNTERED

3.1 Large Terrain dataset management over the web

Virtual Rome has been a challenging project, having faced many still open issues regarding ICT, archaeological and environmental aspects. For some of these problems, we tried to indicate possible solutions.

One of the biggest problem has regarded the management and optimization of the huge available terrain dataset, for its interactive exploration over the Web. More than 35 GB of aerial photographs and satellite images were processed and divided automatically, with a paging technique, in tiles and levels of details, in a similar way as GoogleEarth and NasaWorldWind.

Many of the three-dimensional on line applications today available, based on georeferenced dataset, as in the cases over mentioned, or based on 3d artificial not geographical environments, as SecondLife or other MMORPG computer games, are developed as stand alone software. In these cases, the user downloads the software from the Internet together with main components (sometimes even data and contents need to be downloaded). Virtual Rome, on the other side, is developed as an archaeological net that need to keep the connection with Internet, as sources of further information and interactions and to become an archaeological 3d laboratory on the interpretation of the landscape. For these reasons it has been developed based on OSG4WEB plug-in, as embedded in the browser.

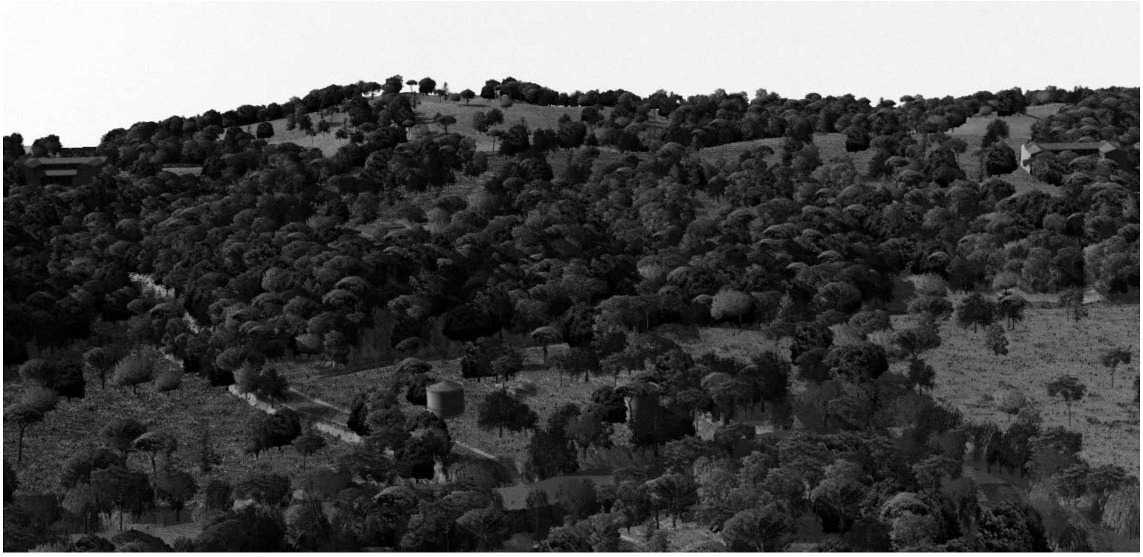


Figure 1 Roman potential landscape: villas (typological models) in the 3d space on the main plateau over the Tiber river [rendering with VNS]

3.2 Models and vegetation optimization

Another problem has regarded the optimization of complex 3d models, such as laser scanned models (initial resolution: 8 mm) or computer graphic models developed for non real-time purposes. Even in this case the goal we wanted to achieve was a fluid exploration of the models inside the territory, avoiding as much as possible interruptions due to download time. This issue was particularly challenging: 15 million of polygons needed absolutely to be optimized, possibly with semi-automatic functionalities! A general adopted solution, to this common problem, is generally to define a really low limit to 3d models dimensions. If the model is treated as a “monolithic” object-file, the result obtained is often unsatisfactory: either it's necessary to have a worst resolution in order to have a fast interaction over the web or a slower interaction and “fluidity” in order to have a better quality and resolution of the model. So: quality or speed? There are actually several techniques that can really help modellers to keep the number of polygons of a models very low, such as render-to-texture effect, lightmaps or other complex shaders. Unfortunately most of them aren't widely supported by computer-graphic cards, or at least not enough, at the moment, for an embed use of an application such as Virtual Rome, whose goal is to point to a wider on-line distribution.

Moreover the limit we fixed for each model was just 300 Kb. For these reasons we adopted also other combined techniques: paging (the model is divided into different units and sub-units, organised hierarchically), levels of detail (every object, geometry and texture, is represented at different LOD in accordance with the scale and distance of the user) and instancing (repetition of same objects in the scene).

At the end every single elements was subdivided in order not to overpass the limit, but without loosing a good final resolution. While in the pasts, adopted solutions preferred to separate macro and micro contexts, thanks to these techniques, it is possible to maintain a perceptive continuity in the exploration both of the macro and micro contexts (figure 2). A similar solution was adopted also for vegetation integration.

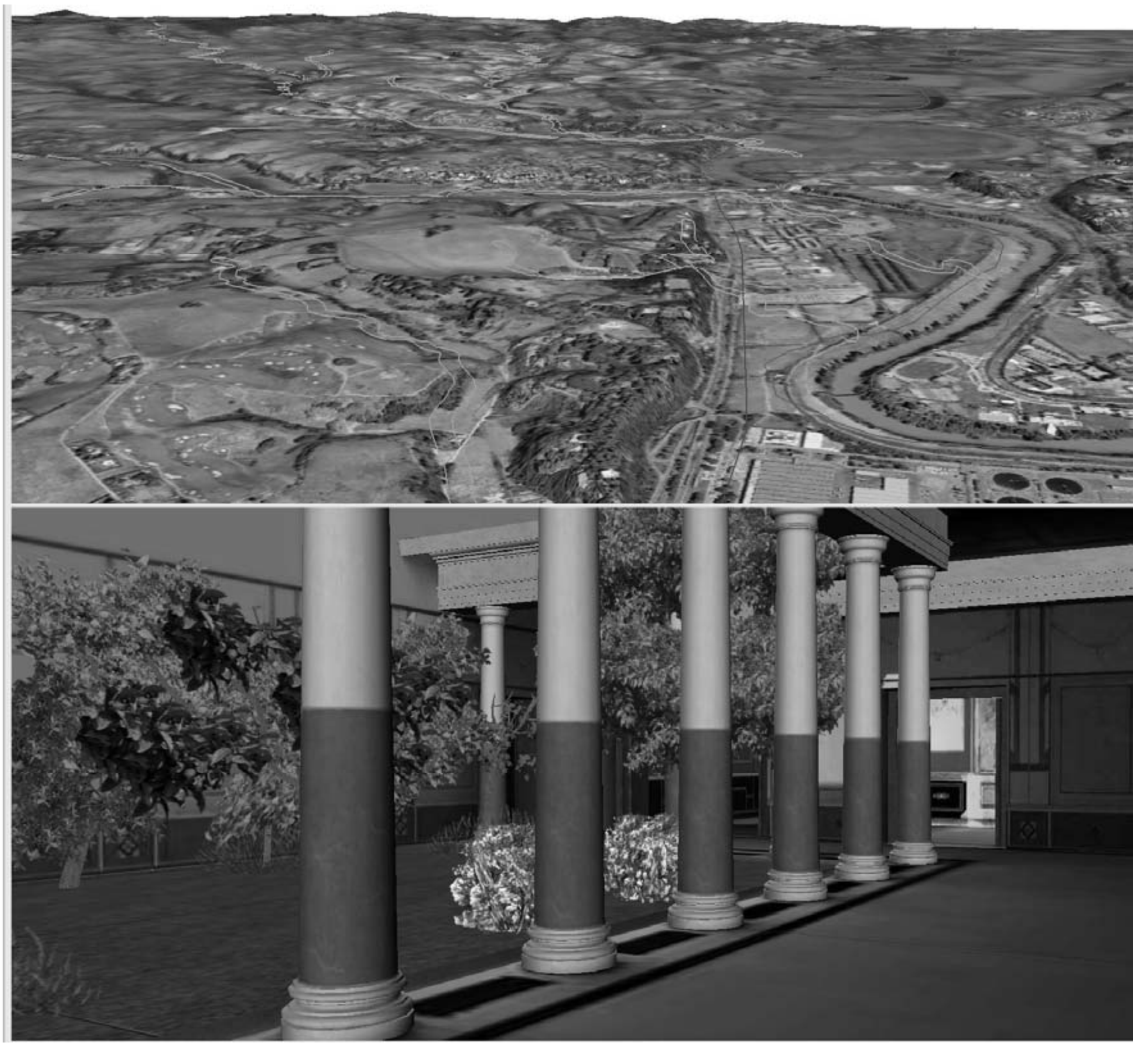


Figure 2 Macro (above) and micro (below) contexts exploration

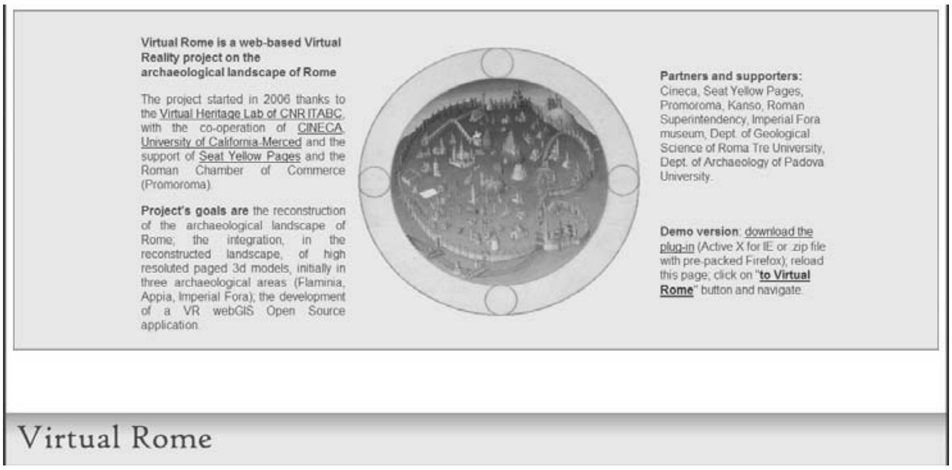
4. MAIN RESULTS

The project required the following activities: development of the software OSG4WEB for interactive exploration over the web, based on open source libraries, mainly OpenSceneGraph; development of software main interface, features and behaviours; the acquisition and processing of 3d surveyed data and other geospecific information; terrain modelling and ecosystem generation of archaeological and potential ancient landscapes; 3d modelling of main archaeological monuments; optimization and integration of other available 3d resources; multimedia contents creation and integration in the 3d space; on line publication of the work.

Main results of the work have been

- The development of an original plug-in, OSG4WEB, based on open source libraries (mainly OpenSceneGraph), embedded in Mozilla Firefox and Internet Explorer browsers for interactive and real time visualisation of complex terrains and other 3d and multimedia contents. The 3d exploration system, based on OSG4WEB open source plug-in and on the OpenSceneGraph library, has a plug-in, cross-platform and cross-browser open source architecture, that enable a transparent integration to web designer in the html page, with Ajax support;
- The software is characterized by an external shell (downloadable by the client) whose goal is also to recall the core (or cores) necessary for a specific application. In the case of Virtual Rome application, the core is connected to OSG library and has to manage basic functionalities connected to 3d window, as navigator window. The interaction between browser and plug-in is based on JavaScript directives, as in the case of buttons an links functions.
- The study, development, optimization and implementation of different contents (2d, 3d and multimedia) regarding the archaeological and ancient potential Roman landscapes.

- The publication of the first release of the web site for Virtual Rome project (www.virtualrome.itabc.cnr.it). The final version will be available starting from September 2008 at www.virtualrome.net (figure 3)
- The development of different "working" on line sections, based on MySql database, PHP and Javascript, used to add and modify dynamically directly in 3d the contents (models, vegetation, behaviours, hyperlinks, points of view, paths). These sections are currently in progress and will be finally integrated in a single back-end structure for "Virtual Rome web-lab".



Virtual Rome is a web-based Virtual Reality project on the archaeological landscape of Rome

The project started in 2006 thanks to the Virtual Heritage Lab of CNR ITABC, with the co-operation of CINECA, University of California-Merced and the support of Seat Yellow Pages and the Roman Chamber of Commerce (Promoroma).

Project's goals are the reconstruction of the archaeological landscape of Rome; the integration, in the reconstructed landscape, of high resoluted paged 3d models, initially in three archaeological areas (Flaminia, Appia, Imperial Fora); the development of a VR webGIS Open Source application.

Partners and supporters: Cineca, Seat Yellow Pages, Promoroma, Kanso, Roman Superintendency, Imperial Fora museum, Dept. of Geological Science of Roma Tre University, Dept. of Archaeology of Padova University.

Demo version: download the plug-in (Active X for IE or .zip file with pre-packed Firefox); reload this page; click on "**to Virtual Rome**" button and navigate.

Virtual Rome

Figure 3 Virtual Rome web site home page.

5. CONCLUSIONS

Due to its high complexity, the project followed a interdisciplinary approach, involving different professionals coming from disciplines such as ICT, archaeology, architecture, paleo-botany, geology, geo-archaeology. It was carried out by ten persons: three programmers, two GIS and terrain experts, four 3d modelers and one graphic expert. Although it still needs a period of tests, we have planned to work, in the future, in a further development of the cooperative on line (back-end) version of the application).

6. ACKNOWLEDGEMENT

People involved in the project are: Scientific direction: S. Pescarin (CNR ITABC), M. Forte (Univ. California); Coordinator landscape reconstruction: S. Pescarin; Coordinator programming: C. Camporesi (CNR ITABC), L. Calori (CINECA); Coord. 3D modelling: A. Moro (CNR ITABC); Landscape reconstruction: A. Palombini and V. Vassallo (CNR ITABC); 3d modelling: F. Galeazzi, M. di Ioia, L. Vico (CNR ITABC), F. Delli Ponti, G. Borghi (CINECA); Programmers: L. Calori, S. Imboden, T. Diamanti (CINECA), C. Camporesi, A. Negri (CNR ITABC); Multimedia contents: E. Pietroni, V. Vassallo, A. Palombini (CNR ITABC); web editing and graphic: M. Pescarin, C. Albano, V. Gottardi

7. REFERENCES

Calori, L., Camporesi, C., Forte, M., Guidazzoli, A., Pescarin, S. 2005. OpenHeritage: Integrated approach to web 3d publication of virtual landscapes, in *Proceedings of the ISPRS Working Group V/4 Workshop 3D-ARCH'2005: "3D Virtual Reconstruction and Visualization of Complex Architectures"*, Mestre-Venice, Italy, 22-24 August, 2005 (S. El-Hakim, F. Remondino, L. Gonzo eds.), Vol. XXXVI, part 5/W17, ISSN 1682-1777

Calori, L., Pescarin, S. 2008. Virtual Rome, in *Poster Section* at *Siggraph 2008 Conference*, in print.

Forte, M, Pescarin, S., Pietroni, E., Rufa, C. 2007. Multiuser Virtual Reality museum application for Cultural Heritage: the Ancient via Flaminia project, in *The 8th International Symposium on Virtual Reality, Archaeology and Cultural Heritage, VAST (2007),* D. Arnold, F. Niccolucci, A. Chalmers (Editors)

Pajarola, R., Gobetti, E. 2007. Survey on Semi-Regular Multiresolution Models for Interactive Terrain Rendering, in *The Visual Computer* 23(8):583–605.

Pescarin, S. 2007. Interpretazione e ricostruzione del paesaggio antico: una proposta di formulazione teorica esplicita, in *La villa di Livia: un percorso di ricerca di archeologia virtuale*, a cura di M. Forte, Ed. «L'Erma» di Bretschneider, 84-100, Roma.

Röttger, S. 2007. NDVI-based Vegetation Rendering, in *Proceeding (553) Computer Graphics and Imaging,* 2007

Röttger, S., Heidrich, W., Slusallek, Ph., Seidel, H.-P. 1998. Real-Time Generation of Continuous Levels of Detail for Height Fields, University of Erlangen-Nuremberg, *In V. Skala, editor, Proc. WSCG '98*: 315-322.

Using digital photogrammetric restitution for the virtual reconstruction of the walls around the 'Titani' acropolis (Greece).

T. Nuttens[1], A. De Wulf[1], R. Goossens[1], C. Tytgat[2], D. Van Damme[1], D. Devriendt[1]

[1]*Geography Department, Ghent University, Krijgslaan 281 (S8), 9000 Gent - Belgium,* timothy.nuttens@ugent.be

[2] *The Netherlands Institute in Athens, Athens – Greece*

Keywords: 3D virtual reconstruction, archaeology, digital photogrammetric restitution, image matching, orthorectification

ABSTRACT: For the further monitoring and managing of the historical site of Titani, different topographic documents were elaborated to offer accurate metric information. Recently (after taking the images in 2005) a small part of the walls collapsed, which proves the need for such metric documents.

So this research focussed on the realisation of Digital Elevation Models (DEMs), ortho-photo maps and a 3D virtual reconstruction of the remnants of the walls around the ancient acropolis of Titani in Greece. The images were taken with a 11 MPixel high-end digital camera, resulting in eighteen stereo-couples which were processed in a highly accurate way with the VirtuoZo^{TM} software. The result of the image matching of the stereo-couple is determinative for the final quality of the ortho-photos and DEMs. Due to a difficult image matching, a special editing procedure had to be elaborated in order to keep the initially strong deformations at the edges of the walls within tolerance.

1 INTRODUCTION

Titani is located about fifty kilometres south-west of Corinth (Peloponnesos – Greece). This ancient site was identified by Ludwig Ross in the 19th century but has remained, so far, a relatively unexplored site. In antiquity, Titani was well known for its sanctuary dedicated to Asclepius, which was one of the earliest centers for practical medicine (Levi, 1982; Meyer, 1937).

This project focusses on the walls around the acropolis. The walls consist of the remnants of two towers, built out of large, rectangular shaped rocks, the other parts of the walls are built out of smaller, irregular shaped rocks. The further conservation of the walls is endangered by different natural and human factors, therefore it was decided in 2005 to document the walls by close range photogrammetry and to elaborate ortho-photo maps, Digital Elevation Models and a 3D virtual reconstruction. The urgent need for such metric information was proven by a partial collapse of the walls in 2006.

2 TOPOGRAPHY – IMAGES

In the period end September – beginning of October, the digital images were taken with a high-end digital camera (Canon EOS 1D – 11 MegaPixel). This is a non-metric camera, so the lens distortions are unknown and the image has no grid. But even with this non-metric camera, it is possible to obtain very accurate results in the photogrammetric restitution. The remnants of the walls were photographed with a minimum 60% overlap, avoiding direct sunlight, big shadow parts and places with little or no contrast. In total, there were eighteen stereo-couples recorded, with a minimum of six ground control points in the overlapping area of each stereo-couple.

These ground control points are little pieces of a light cardboard material, which are placed upon the walls. We chose not to use characteristic points of the walls as ground control points, to avoid mistakes pointing out the ground control points during the absolute orientation. The ground control points are measured with a total station, from the base stations of a topographic polygon around the remnants of the walls. This polygon is connected with a geodetic point on the acropolis, so that the coordinates of the ground control points are known in an absolute coordinate system.

3 DIGITAL PHOTOGRAMMETRY

In archaeology and architecture, close range photogrammetry is a valuable alternative to obtain metric documentation about objects. Due to the complexity of the objects or historical artefacts, a rough and hardly accessible terrain and limited viewing points, it can be much easier to take photographs of the objects than to measure them completely with a total station. The digital images provide not only a possibility to retrieve metric information, but provide also the complementary semantic information (Atkinson, 1980).

3.1 *Coordinate transformation*

Before starting with the photogrammetric restitution for each stereo-couple, we have to perform a coordinate transformation on the coordinates of the ground control points. As the coordinates of the ground control points are known in a general coordinate system, we have to transform them to a new local coordinate system per stereo-model. In this local coordinate system, the X-axis is as parallel as possible to the wall, which makes that the Y-axis points upwards and the Z-axis is pointing towards the observer. The coordinate transformation is partly performed in advance, with the Transcad software and partly in the VirtuoZo^{TM} software.

The ortho-photos have to be fit together in the end for the virtual reconstruction, which implies that we then have to perform an analogue - but reverse - coordinate transformation to place them all together in a general coordinate system.

3.2 *Relative Orientation*

The digital photogrammetric restitution was performed with the VirtuoZo^{TM} software. The stereo-models in this project were processed in a non-metric way, which means that there was no internal orientation during the photogrammetric process. The relative orientation is automatically implemented, but it is important that the operator still checks the results of the search for homological points. The operator has to check if the indicated points are really homological on both images and if the RMS-error doesn't exceed the limit of 0.005 millimetres.

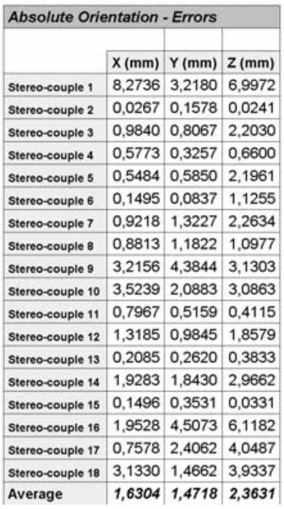
To continue with the photogrammetric restitution, there have to be at least 100 to 150 homological points indicated. In ideal cases, the software finds all of these points automatically, but in most stereo-models in this project, there had to be extra points manually picked out by the operator. This manual selection will be less precise than the automatic selection, so the operator has to make sure that the RMS-error doesn't exceed the limits. It is also very important to spread the homological points as well as possible over the overlapping area of the stereo-model.

The two towers of the walls are built out of large, rectangular shaped rocks and the images of these towers have more contrast and are taken from a better and closer point of view, which makes that these stereo-models cause less problems during the relative orientation. The importance of a good relative orientation and enough well-spread homological points will be explained later, with the image matching.

3.3 *Absolute Orientation*

By pointing out the ground control points within the overlapping area, the operator can place the stereomodel in an absolute coordinate system. When there are at least six points, the software calculates the errors in X, Y and Z for each ground control point and the average values (Manzer, 1996). The operator can manually deselect certain ground control points to improve the error results, for example if the ground control point can not be unambiguously indicated on both images.

The error results shown in the table below are the average results for each stereo-couple in millimetre. The very small results (< one mm) have to be interpreted as a very accurate result, without focussing on the real value of the error, because it is too small to have a rational meaning. The maximum error value that was fixed at the start of this project was one centimetre, and the results never exceeded this value.



Absolute Orientation - Errors

	X (mm)	Y (mm)	Z (mm)
Stereo-couple 1	8,2736	3,2180	6,9972
Stereo-couple 2	0,0267	0,1578	0,0241
Stereo-couple 3	0,9840	0,8067	2,2030
Stereo-couple 4	0,5773	0,3257	0,6600
Stereo-couple 5	0,5484	0,5850	2,1961
Stereo-couple 6	0,1495	0,0837	1,1255
Stereo-couple 7	0,9218	1,3227	2,2634
Stereo-couple 8	0,8813	1,1822	1,0977
Stereo-couple 9	3,2156	4,3844	3,1303
Stereo-couple 10	3,5239	2,0883	3,0863
Stereo-couple 11	0,7967	0,5159	0,4115
Stereo-couple 12	1,3185	0,9845	1,8579
Stereo-couple 13	0,2085	0,2620	0,3833
Stereo-couple 14	1,9283	1,8430	2,9662
Stereo-couple 15	0,1496	0,3531	0,0331
Stereo-couple 16	1,9528	4,5073	6,1182
Stereo-couple 17	0,7578	2,4062	4,0487
Stereo-couple 18	3,1330	1,4662	3,9337
Average	***1,6304***	***1,4718***	***2,3631***

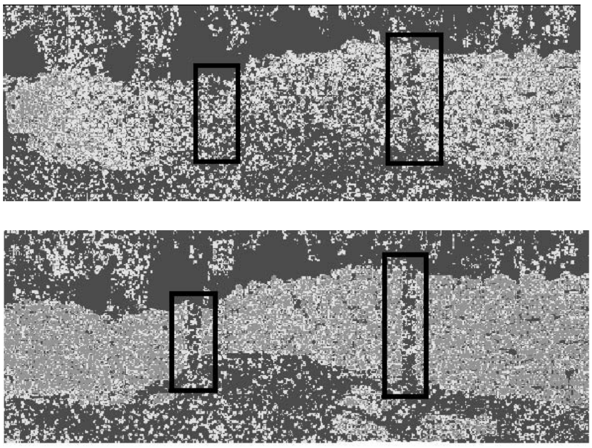
Table 1: Errors on the Absolute Orientation(Own research)

3.4 *Image Matching*

The following steps in the photogrammetric process go automatically. The epipolar images have no more parallaxes, except for the X-parallax. The difference in X-parallax between two points is calculated during the image matching, as an indication of the relative height difference (Mikhail *et al.*, 2001). The image matching in the VirtuoZo^{TM} software is based on an area-based and feature-based matching, implemented in an image pyramid. In a feature-based matching algorithm, the form characteristics of both images are compared, where an area-based matching algorithm is based on the comparison of the grey value of the pixels. These two matching algorithms are combined in an image pyramid method, with a series of images of the same object but with different resolutions, until a maximum correlation is reached in the image with the highest resolution.

As already mentioned, the quality of the result of the image matching depends largely on the number of homological points and their spreading in the overlapping area. The result of the image matching on its turn, affects largely the quality of the Digital Elevation Model and the ortho-photo. The quality of the result of the image matching is represented by coloured 'pegs'. The green 'pegs' indicate a very good matching result, in areas with red 'pegs' there was little or no image matching possible. Yellow 'pegs' indicate a "medium good" image matching.

Figure 1: Example of bad image matching (upper example) – example of very good image matching (lower example) (Own research)



The example gives an illustration of a part of the walls that has been processed two times. The upper example shows the result after the image matching, when there have been no extra homological points selected by the operator. The automatically selected homological points (forty points) aren't sufficient in number and aren't sufficiently spread over the image, so the result of the image matching is not acceptable for further processing. When the operator manually selects extra homological points (182 points) and makes sure that the points are well-spread over the image, the result of the image matching is much better and certainly acceptable for further processing. This is the lower example.

The images show also two areas on the wall with no image matching. These are the places on the left and right picture were the tree in front of the wall was projected. On each image there is a little area - behind the tree - with no information of the wall and so no image matching is possible on that area.

3.5 *Editing*

The Digital Elevation Models and ortho-photos are automatically generated, but the level of detail and the resampling method have to be selected by the operator. The information about the final products, their accuracy and other information about the complete photogrammetric process (errors on relative and absolute orientation, image matching…) is given by the 'Quality Assistance Report'.

The Digital Elevation Models and ortho-photos can present deformations, but these deformations can manually be corrected by the operator by editing the height value for specific pixels. Especially the edges of the walls can show strong deformations, due to the large difference between the height value of the wall and the height value of the adjoining pixels of the background. It looks like the edges of the wall are torn towards the background, as shown in the example. By editing the height value of the background to a value closer to the one of the wall, the height difference and so the deformations are decreased.

The operator performs this special editing procedure by selecting an area of pixels and choosing an interpolation function to calculate the new height value or manually filling in the new height value.

The background contains no important information for the Digital Elevation Models or the ortho-photo maps, so changing these height values doesn't influence the final results.

4 RECONSTRUCTION

The three dimensional reconstruction of the remnants of the walls is performed with the AutoCAD (Autodesk) software. For this reconstruction, all of the eighteen ortho-photos are imported in AutoCAD and placed on the correct 3D coordinates. In order to combine all of the ortho-photos in the same coordinate system, the operator has to perform a new coordinate transformation for each stereo-model from the local coordinates to new coordinates in a general coordinate system.

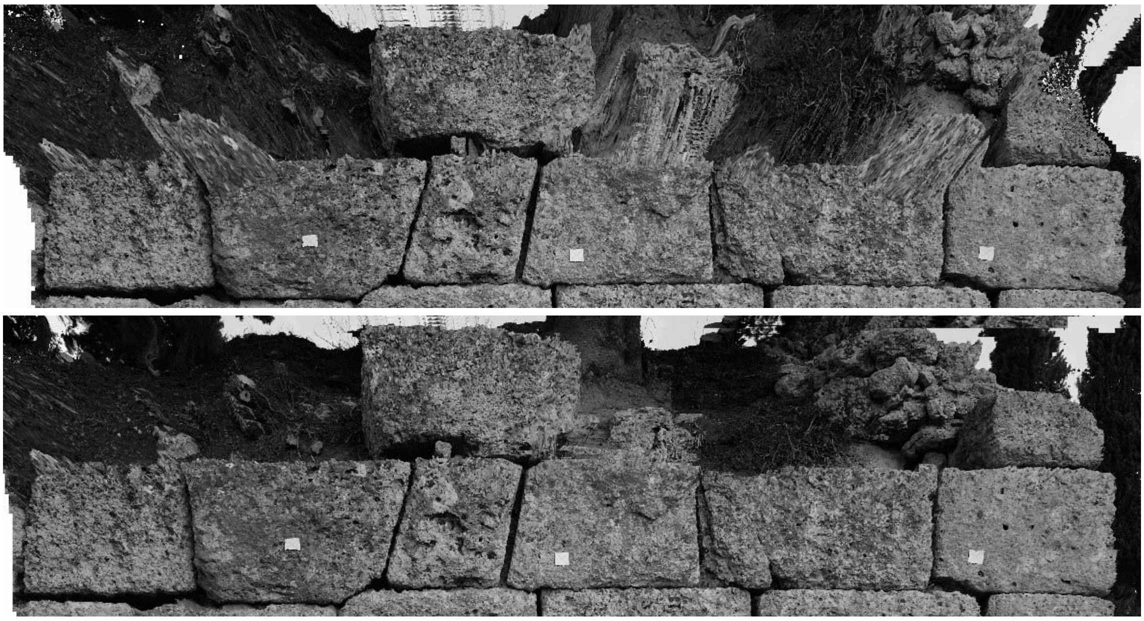


Figure 2: Deformations at the upper edge of the wall before editing (upper example) – after editing (lower example) (Own research)

5 CONCLUSION

The results of this project (Digital Elevation Models, ortho-photo maps and the virtual reconstruction) are important metric documents for further managing, documentation, conservation and restoration of the walls around the acropolis of Titani. The importance of having such metric documentation has recently been proven by a partial collapse of the wall.

A lot of problems appeared during the photogrammetric restitution, but solutions were found to obtain accurate final results. A lot of problems were due to insufficient contrast in the images, non-ideal viewing points on the rough terrain or the scale difference between the two images of a stereo-couple. In most of the cases, there also had to be extra homological points manually selected to obtain an acceptable result for the relative orientation and the image matching.

Finally, the conclusion is that this workflow delivers the required results, without exceeding the error limits.

6 ACKNOWLEDGEMENTS

A part of the research and support for this project was also performed by Marc Hennau, a Ph.D. Student at the moment of this study.

7 REFERENCES

Atkinson, K. B. (Ed.), 1980. *Developments in Close Range Photogrammetry-1.* Applied Science Publishers Ltd., London.

Levi, P. 1982. *Atlas of the Greek World*, Equinox Ltd., Oxford.

Manzer, G. 1996. Avoiding Digital Orthophoto Problems, Greve, C. (Ed.), *Digital Photogrammetry, An Addendum to the Manual of Photogrammetry, American Society for Photogrammetry and Remote Sensing*, Bethesda Maryland, p. 158-162.

Meyer, E. 1937. *Peloponnesische Wanderungen. Reisen und Forschungen zur antiken und mittelalterlischen Topographie von Arkadien und Achaia*", p. 11-16; map I; pl. II-IV.

Mikhail, E., Bethel, J. S., McGlone, J. C. 2001. *Introduction to Modern Photogrammetry*". John Wiley & Sons, New York.

Development of integrated 3D methods for the creation of a DVR-based knowledge platform

F. Gabellone, I. Ferrari, F. Giuri, M. Limoncelli

IBAM ITLAB, CNR Consiglio Nazionale delle Ricerche, Lecce, 73100, Italy, f.gabellone@ibam.cnr.it

Keywords: Virtual Reality, Laser Scanning, Distance Visiting, Desktop Virtual Reality (DVR)

ABSTRACT

This study is one of the activities organised as part of the ByHeriNet project (“Byzantine Heritage Network: Rehabilitation, highlighting and management in the Eastern Mediterranean Basin”), promoted under the EU Programme known as INTERREG III B “ARCHIMED”.

The main objective of the activities of the IbamITLab within the ByHeriNet project is the development of integrated methods for the creation of three-dimensional models using laser scanning techniques, digital photogrammetry, 3D photomodelling and direct surveying, applied to Byzantine sites in the province of Lecce and the region of Basilicata in the South of Italy.

The three-dimensional models established using these methods constitute an advanced information platform, able to represent the architectural morphology of the buildings under study with great accuracy at various scales, including both detailed elements and the monumental arrangement as a whole, as well as the textural features of the internal and external surfaces.

The main aim of this study is to enable the public to enjoy the results of archaeological and archaeometric research, via the web or stand-alone products, and to “virtually visit” the monuments using RealTime 3D visiting systems. The navigation platform allows the user to visualise complex scenes and DVR-based knowledge models in “full-screen mode” even on desktop computers. As well as showing the current state of the monuments, the visit includes reconstructions of previous phases in their history and virtual restorations of the Byzantine paintings. All the textures were obtained by processes of photomodelling and were applied to the geometrical forms in accordance with the radiosity algorithm, with lights and shadows of the ‘area’ type. The result is extremely life-like, almost indistinguishable from reality.

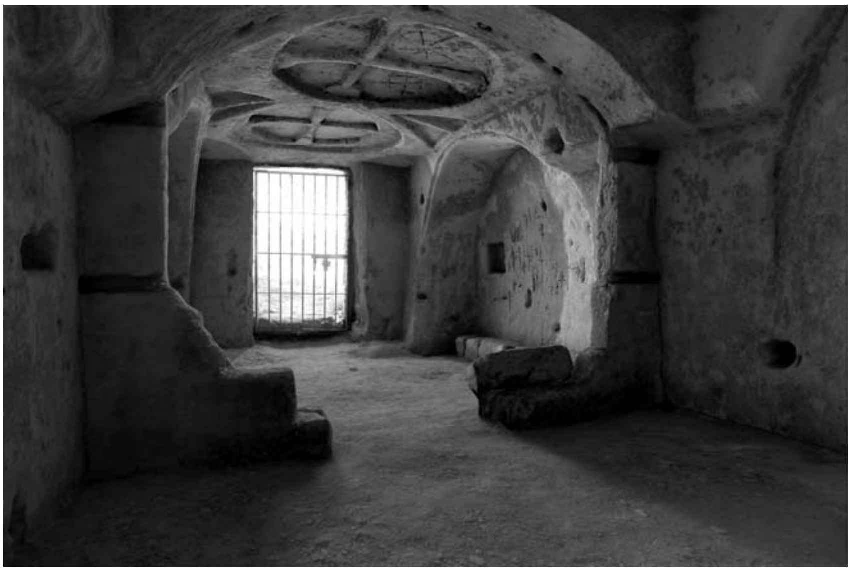


Figure 1: 3D restitution from laser scanning and Camera mapping of Madonna delle Croci church (Matera, Italy).

1. OBJECTIVES

The main objective of the Italian National Research Council’s IbamITLab in the context of the By-HeriNet project is the development of integrated methods for the creation of three-dimensional models using laser scanning techniques, photogrammetry and 3D photomodelling, applied to Byzantine sites in the province of

Lecce and the region of Basilicata, with particular reference to those monuments with elements of special interest that are representative of the period in question.

The three-dimensional models developed using the integrated methods described below provide a use-ful knowledge base for representing architectural morphology on various scales with great accuracy. This includes both specific details and the overall monumental arrangement, as well as the textural characteristics of the interior and exterior surfaces.

Each monument was modelled and studied in relation to its environmental context, noting its underly-ing system of relationships, which is often the key to understanding the architectural strategies adopted. The main goal of this research however remains that of allowing the public to benefit from the results obtained, either via the web or stand-alone products, so that they may "visit" and enjoy the monuments using both 3D RealTime visiting systems and spherical and interactive 3D panoramas. Each three-dimensional model is thus integrated in a multimedia authoring system in which all the data formats available for the item in question (audio, video, VRML, QTVR, VR-Object, images, ta-bles, etc.) can be combined in a single environment. Descriptions of an academic and critical nature (historical overview, relations with other ancient contexts, exegetical analysis, etc.) are combined with technical and scientific methods of analysis and diagnosis (e.g. analysis of constituent materials, state of conservation, study of architectural characteristics, etc.).

In an interactive environment, it is possible to interact with the structures of the sites under study and search the associated Databases for drawings of the layout, topographical data, orthophotos and his-torical documents, together with information on the mineralogical and petrographic characteristics of the construction materials, plasters and paintings. The virtual visit is further enriched with CG (Com-puter Graphics) reconstructions that provide the user with a diachronic reading of the monument and enable him/her to better understand the transformations it has undergone.

The process of creating content relating to each monument studied may be summarised as follows:

1. Gathering of the historical documentation available;
2. Architectural survey of the structures, performed with methods appropriate to the distinctive characteristics of each monument;
3. Three-dimensional restitution and optimisation of the models in accordance with the predicted out-puts;
4. Extraction of the two-dimensional maps and video footage to be integrated in the computer vision systems or in the stand-alone publishing products (DVD Videos, VRML models, etc.)
5. Creation of virtual spherical panoramas (QTVR);
6. Implementation of the 3D models and QTVR contributions in VR knowledge platforms.

3. FIRST CASE STUDY: THE ABBEY OF S.M. DI CERRATE

The Abbey of Santa Maria di Cerrate, situated in open countryside in the municipality of Squinzano, a few kilometres North of Lecce, was founded at the beginning of the 12th century by Norman counts.

The aims of the architectural survey of the Abbey of Santa Maria di Cerrate are to document the current state of the building and construct the three-dimensional models necessary for the development of the knowledge platforms described above. Consequently, the survey operations concerned not only the individual surfaces of the church itself, but also the series of buildings that encircle the Abbey today in a "defensive wall" and form an inseparable part of the same monumental complex. Given this premise, the early phases the work focused on the acquisition of the basic photographic documentation and on the choice of appropriate techniques for the restitution of the monumental complex at a high level of detail and precision. As already mentioned, considering the aims of the communication products and the survey issues specific to this case, it was readily perceived that these requirements could be met by restitution techniques based on digital photogrammetry and photomodelling in particular.

The reasons for this choice obviously include their greater flexibility and ease of use compared to normal photogrammetric techniques, but above all the possibility they provide of obtaining three-dimensional models of great precision at very low cost (rif. Low cost met, CIPA). In this specific case, it should be stressed that the surveying difficulties resulting from the height of the buildings, together with the problems of accessibility to certain architectural elements (the rose, roofs, upper windows, etc.), mean that considerable effort (and additional costs) would have been required for the deployment of of the equipment necessary for a traditional photogrammetric survey. Given the conditions, the adoption of a system based on laser scanning was also excluded a priori, in that this would have required greater processing times in terms of post-editing and would have generated redundant data for the flat surfaces. In an architectural survey with specific aims such as this one, the key factor is the critical judgement of the surveyor, who must identify, by means of a careful analysis of the architectural elements, only the essential points necessary for the restitution. This critical evaluation, which entails the recognition of corresponding points in different photographic shoots, is also the fundamental task in photomodelling surveys. In operational terms, it is sufficient to identify the vertices of each architectural element, or insert some targets on the surface being surveyed in the poorly characterised areas, in order to obtain three-dimensional models complete with textures mapped in UVW projection.

4. SECOND CASE STUDY, THE RUPESTRIAN CHURCH OF MADONNA DELLE CROCI

Entrance to the crypt is through a round arch with a simple rectangular door in the centre of a semicir-cular façade carved in the rock which contains a series of niches and engraved crosses. The interior, rectangular in shape and oriented East-West, is subdivided into two vaults separated by a segmental diaphragm arch. Each vault is supported at the sides by blind arches where, in the vault closest to the entrance, numerous crosses are engraved.

The survey of the internal walls of the crypt was performed with an time of flight laser scanner. The acquisition was based on domes of about six metres in radius, with a level of detail of the point clouds of 2-4 mm. Five scans were necessary, three inside and two outside, to describe the entire item with a good coverage of the undercuts.

The scanner proved to be fast and reliable, but the editing of the point clouds required a considerable effort on the part of the operator to resolve problems caused by exporting in the dxf format, which resulted in pronounced anomalies and discontinuities in horizontal bands at regular intervals. In each case the manipulation of the meshes using software dedicated to the management of point clouds resolved the problem satisfactorily, and the results are visible in the images shown in this article. The polygonal mesh was subsequently decimated in order to maintain the number of polygons within a limit that was empirically tested on normal consumer computers, in the order of 400-500 thousand polygons. In the texturing phase, this limit, imposed for reasons linked to the performance of the Realtime engine, considerably simplified the selection of the groups of faces to which each individual material was assigned. The internal walls were mapped using the Camera Mapping method, well-known and used in cinematography, but rarely used in other applications such as the restitution of monuments.

Our experience has shown the excellent performance of CM on curved surfaces, for example the apsidal wall or the underside of the arches of the lateral walls; on all the other surfaces an extensively subdivided planar projection was used, again to limit distortions in the undercuts as much as possible.

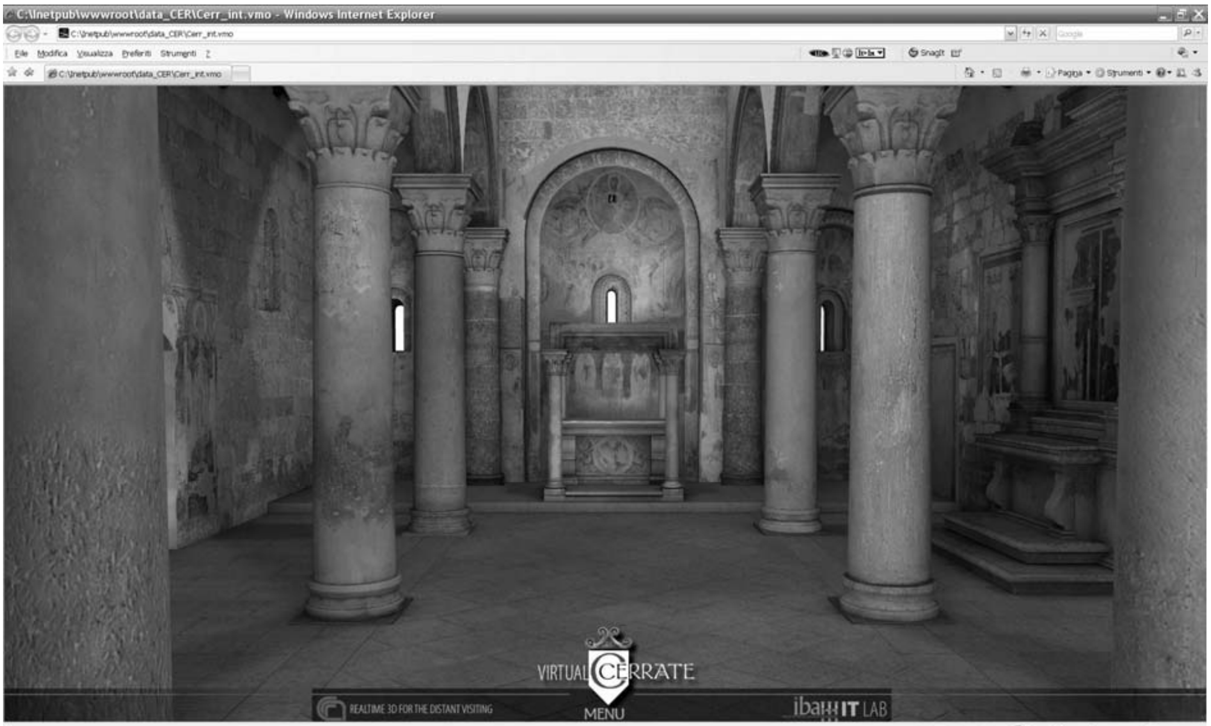

C:\Inetpub\wwwroot\data_CER\Cerr_int.vmo - Windows Internet Explorer
File
Modifica
Visualizza
Preferiti
Strumenti
?
VIRTUAL CERRATE
MENU
REALTIME 3D FOR THE DISTANT VISITING
ibam IT LAB

Figure 2: A screenshot of DVR platform with his navigation interface. Interiors of S. M. di Cerrate abbey.

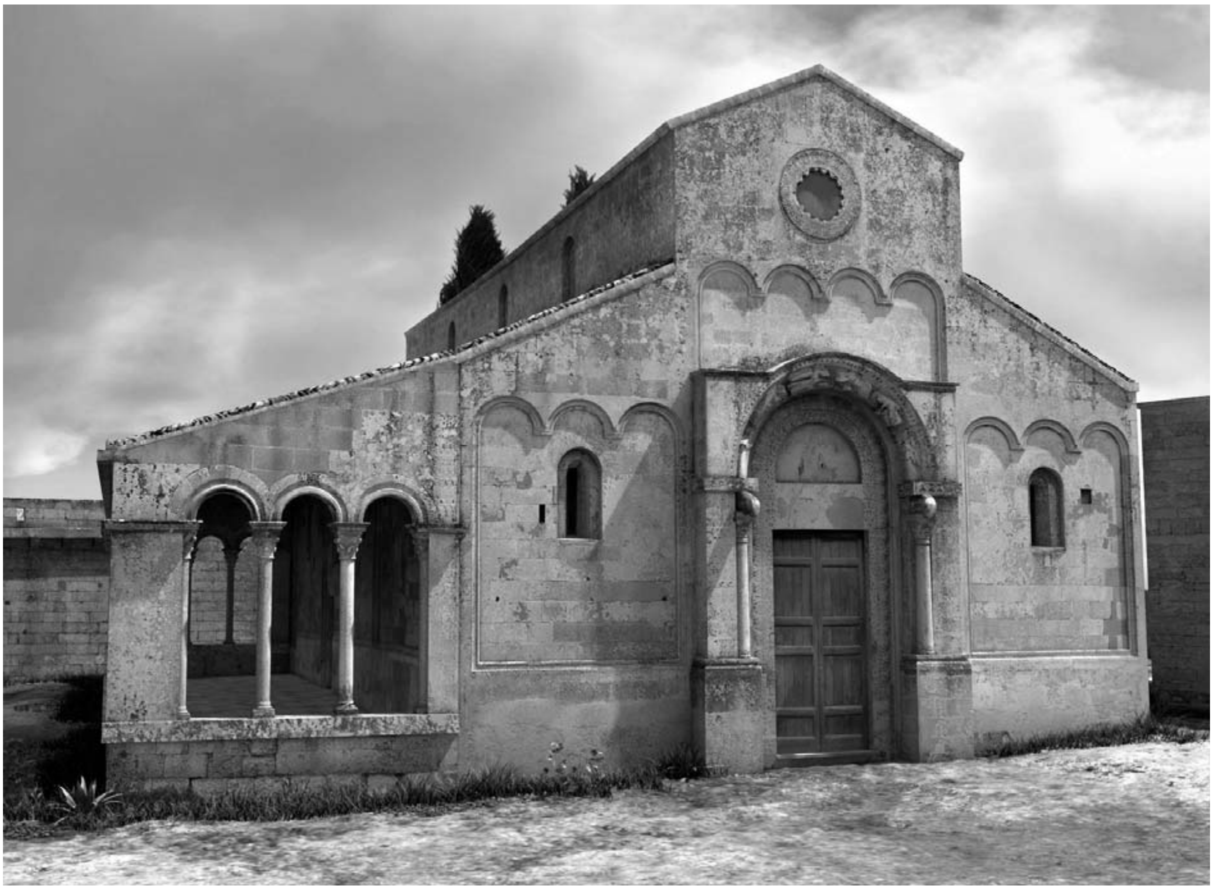


Figure 3: 3D restitution from photomodelling approach of S. Maria di Cerrate abbey.

REFERENCES

Lévy P. 1997. *Il Virtuale*, Raffaello Cortina Editore, Milano

Fonseca, C.D., Roubis, D., Sogliani, F. 2007. *Jure Vetere. Ricerche archeologiche nella prima fondazione monastica di Gioacchino da Fiore (indagini 2001-2005)*, Soveria Mannelli.

Gabellone, F., Giannotta, M.T. 2005. R*ealtime 3d multimedia system for the distance visiting of cultural heritage. A case study on the chamber tombs in via Crispi, Taranto*, XX CIPA International Symposium, International Cooperation to save Cultural Heritage, Torino.

Gabellone, F., Giannotta, M.T., Monte A. 2001. *Nurbs Modelling for the conservation of ancient Buildings, in 2nd International Congress on Studies in Ancient Structures*, Istanbul 9-13 July.

Rossi, M,. Salonia, P. 2003. *Comunicazione multimediale per i beni culturali*, Addison Wesley, Milano.

Computer Graphic Modelling at Portus: Analysis, Reconstruction and Representation of the Claudian and Trajanic Harbours

G.P. Earl[1], S.J. Keay[2], G.C. Beale[3]

1 Archaeological Computing Research Group, University of Southampton, UK, SO17 1BF, email: graeme.earl@soton.ac.uk
2 British School at Rome, Italy, 00197, email: S.J.Keay@soton.ac.uk
3 Archaeological Computing Research Group, University of Southampton, UK, SO17 1BF, email: gcb205@soton.ac.uk

Keywords: Computer Graphics; Virtual Archaeology; Roman Ports; Portus

ABSTRACT

This paper discusses the application of computer graphic modelling techniques to the site of Portus, Rome. Computer modelling forms a fundamental component of this project, with models generated as the archaeology is uncovered through excavation and advanced survey methods, in particular volumetric and conventional forms of geophysical prospection. The project employs professional software for the production of recreated palaeo-environments, building exteriors and interiors, and the fragmentary artefacts associated with the site.

These computer models serve a number of purposes. First, to develop and stimulate discussions on site relating to new data as the excavation and survey continue. Second, to provide the focus for discussions relating to the reconstructed form of surveyed and excavated buildings and landscapes. Here the models act as a locus for debate between a range of architectural and archaeological professionals. Third, to develop an environment within which to build interpretations relating to the form and function of Portus and its surrounding landscape, throughout its development and decline. Finally, to communicate the results of ongoing and previous fieldwork and interpretations to a wider public, and to experts.

1 INTRODUCTION

The Portus Project is focused on a programme of excavation and survey carried out on the site of Portus, the ancient port of Rome. It is directed by staff from the British School at Rome, and the Universities of Southampton and Cambridge, and funded by the Arts and Humanities Research Council (AHRC) and the *Soprintendenza Archeologica di Ostia,* with support from the Duke Sforza Cesarini. The project builds on a large area survey in and around Portus begun in 1998 that employed a range of geophysical techniques (Keay *et al.*, 2005). The use of computational techniques forms an additional focus for the project, with current work directed towards the development of efficient textual, spatial and numerical database management systems, the use of polynomial texture mapping as a surface recording technique, laser scanning of objects and structures, and computer graphic modelling.

Computer graphics have had a long association with Roman archaeology and architecture. Initial applications were focused solely on the demonstration of novel computational techniques. Subsequently the representative potential of professional modelling software such as 3ds Max, Vue Infinite, Poser and Maya were harnessed in order to present a range of interpretations. Still more recently the focus has once again shifted towards the analytical use of computer modelling, in order to test hypothesized spatial interactions, to analyze structural capabilities, and to consider human scale interactions within constructed places (Haselberger & Humphrey, 2006).

2 INTEGRATION WITH FIELD PRACTICE

The use of computer graphic representations in archaeology often marks the culmination of a process of data gathering, interpretation, re-analysis and synthesis. At Portus we have attempted to integrate the development of these visual representations with day-to-day archaeological field practice. As a consequence the data gathering does not merely inform a pristine, completed final representation but rather participates in a reciprocal series of debates on and off-site. It is hard to quantify the impact of this on the process of excavation and survey but it is clear that the creation and negotiation of visual parallels to archaeological primary data stimulate debate amongst project participants at a very early stage. It is also the case that this model construction *is* archaeological practice: it is rigorous, analytical, and as a consequence must embody the same ambiguities. Such models may take the form of three-dimensional views of the excavated site as it grows and as the interpretation of its phasing develops (figure 1; left). Alternatively it may be the construction of *visual arguments* (as in figure 1; right) employed to stimulate further discussion.

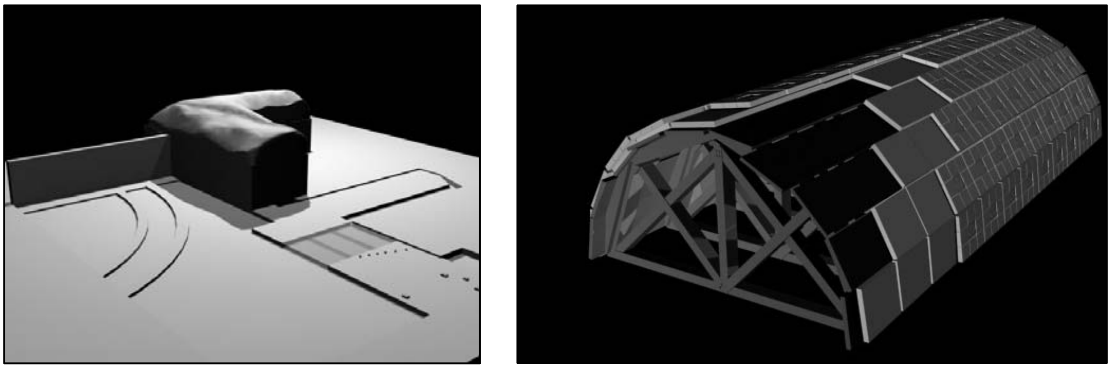


Figure 1. Volumetric models used in the field for analysis of excavation and geophysical data: (left) model of the 2007 excavation area; (right) modelled interpretation of cistern construction.

3 BUILDING DISCUSSIONS: SEVERAN MAGAZZINI ACCESS

Computational models provide a visual correlate to physical objects, but at the same time they can provide access to now invisible spaces and also enable physical analyses where little structure survives (Ciechomski, 2005; Earl, 2007). At Portus we are beginning to employ both aspects of this analytical potential. Primarily, we are addressing questions of human interactions with and within the built environment of Portus. For example, in our completed study of the so called *Severan Magazzini*, a substantial range of warehouses thought in fact to have been constructed during the reign of Marcus Aurelius, we have considered the range of possible access to different areas of the building, and also the structural implications of given access routes (figure 2). This has been made possible through the amalgamation of a range of data sources, qualified not only by the input of a number of expert architectural historians but also by considerations of structural principles (Rickman, 1971; Wilson-Jones, 2000). Such approaches form a useful counterpoint to plan-based analytical approaches to Roman space, which are increasingly critiqued for their separation from lived realities (Allison, 2001).

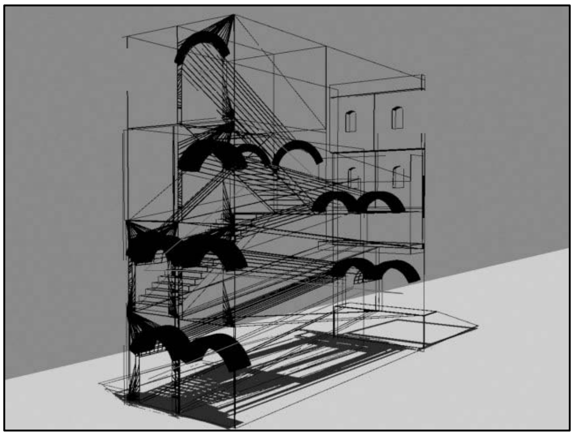


Figure 2. Analytical use of computer graphic modelling in the assessment of access to the Severan Magazzini from the Trajanic basin

4 BUILDING INTERPRETATIONS: SEVERAN MAGAZZINI EXTERIORS

Structural analyses in turn lead to a broader understanding of the possible architectural forms. Such analyses are used alongside conventional architectural history techniques to propose completed buildings. With each step in the representative process additional complexities are added, and the distance between archaeologically attested fact and representative fiction expands. This divide, perhaps best represented in the work and discussions centred around Alan Sorrell's exquisite painted representations of Roman architecture (Sorrell, 1981) has received a great deal of attention in the archaeological computing literature. Issues of authenticity and in particular the need to present uncertainty in a transparent fashion dominate. In our work at Portus we have opted to present completed visual interpretations and sufficient documentation as to their origins for colleagues and non-specialists to critique our work, without diminishing the visual impact of the models.

The facades of the reconstructed Severan Magazzini (figure 3) represent the most speculative and spectacular aspects of such modelling work on site. Far from being a weakness this is their greatest strength. They maximize potential engagement of all participants both in the Portus project and in wider debates relating to Roman architecture. Already, the presentation of initial ideas surrounding the building in specialist and non-specialist fora have stimulated active and informed discussions. They provide a tangible, if partial partner to what are otherwise abstract descriptions of Roman architectural form and function.

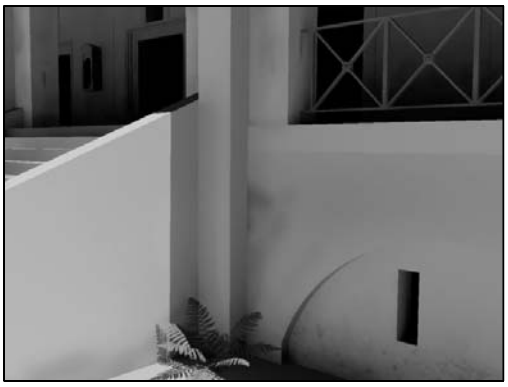


Figure 3. Computer graphic still from the model of the Severan Magazzini

The modelled facades also provide for the opportunity to experiment, providing multiple representations of the building. Beyond the three examples illustrated below, a vast number of permutations are made possible and rendered accessible to the viewer by thoroughly documented use of a range of professional computer modelling packages (figure 4).

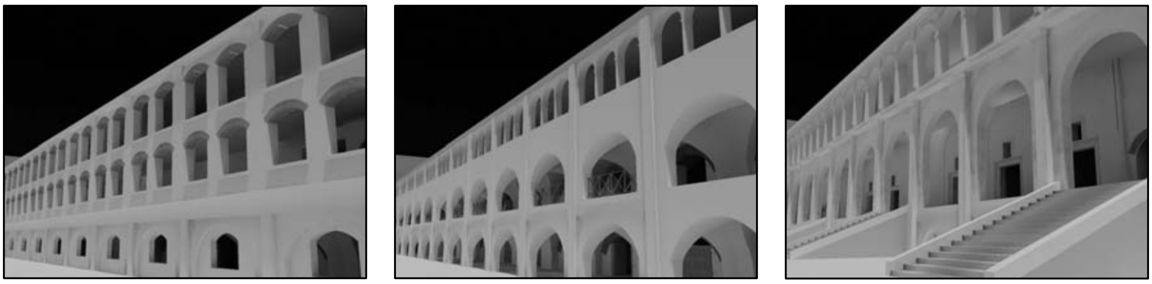


Figure 4. Computer graphic still from the model of the Severan Magazzini showing three alternative architectural scenarios

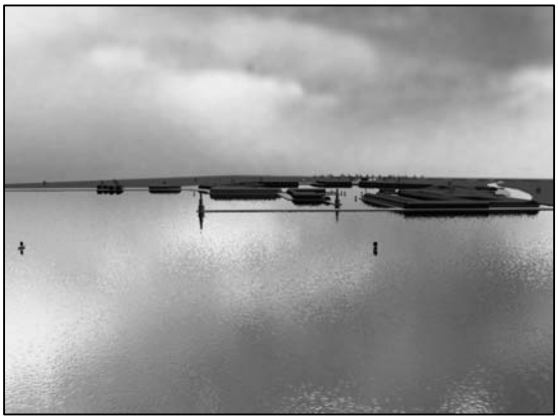


Figure 5. Screenshot from the computer graphic model produced on the basis of the geophysical survey of Portus (Keay et al., 2005)

5 COMMUNICATION: PORTUS DISSEMINATION PROJECT

Communication of archaeological work to as wide an audience as possible is core to the activities undertaken both under the aegis of the Portus Project, and the preceding survey. To this end a relatively simple computer graphic model was produced in 2005 (Keay, 2006). This demonstrated the favoured interpretations of the geophysical data and standing remains recorded on site and was structured around a series of five tours of the harbour in the Claudian, Trajanic and Late Antique phases of the site's development. We have now begun considerably to enhance the models underlying these tours, employing a range of computer graphics techniques more commonly associated with film animation.

The existing tours are available via the Portus Project website. Our newer modeling work will similarly be disseminated online, employing standard animation techniques in addition to interactive models. However, we have also now begun to develop a travelling exhibition. This will incorporate stereo versions of our high resolution animations, viewable via a passive stereo projection system and special viewing glasses.

6 CONCLUSIONS

Computer graphic techniques have a great deal to offer all aspects of the archaeological process. At Portus we are only beginning fully to realize their potential but it is clear that the opportunity to visualise archaeological data in their native three-dimensions, and to build upon them through careful interpretation will move studies of Roman architecture and archaeology in new and exciting directions. Already we have developed new ways of integrating the modelled virtual with the excavated reality and to learn as much through the practice of digital archaeology as through the visualisation of our fieldwork data.

Further details about the Portus Project can be obtained from www.portusproject.org

7 REFERENCES

Allison, P.M. 2001. Using the Material and Written Sources: Turn of the Millennium Approaches to Roman Domestic Space, *American Journal of Archaeology*, 105 (2) : 181-208.

Beale, G.C. 2007, *An Archaeology of the Mundane: Interpretation and reconstruction of the Grandi Magazzini di Settimio Severo at Portus, Italy*. Unpublished MSc dissertation. University of Southampton.

Ciechomski, P, Ulincy, B, Cetre, R., Thalman, D. 2005. *A Case Study of a Virtual Audience in a Reconstruction of an Ancient Roman Odeon in Aphrodisias*. In K. Cain, Y. Chrysanthou, F. Niccolucci, N. Silberman (Eds) Proceedings from the 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2004). Brussels: ENAME.

Earl, G.P. 2007. *De/construction Sites: Romans and the Digital Playground*. In Bowen, J., Keene, S. and MacDonald, L. (eds.) EVA 2007 London Conference Proceedings. Hampton Hill, UK, EVA Conferences International.

Haselberger, L., Humphrey, J H. 2006. *Imagining Ancient Rome: Documentation - Visualization - Imagination*. Proceedings of the Third Williams Symposium on Classical Architecture. JRAS, 61.

Keay, S., Millett, M., Paroli, L., Strutt, K. 2005. *Portus: An Archaeological Survey of the Imperial Port of Rome*. Archaeological Monographs of the British School at Rome.

Keay, S., 2006. Portus. *Current World Archaeology*, 20 : 11-20.

Rickman, G. 1971. *Roman Granaries and Store Buildings*. Cambridge University Press.

Sorrell, A. 1981. *Reconstructing the Past*. Batsford Academic and Educational, London.

Wilson-Jones, M., 2000. *Principles of Roman Architecture*. Yale University Press, London.

3D perspective views and their applications to Archaeology: A case study on the site of Badami

M.B. Rajani[1], S.K. Patra[2], Mamta Verma[3]

1 National Institute of Advanced Studies (NIAS), Indian Institute of Science Campus, Bangalore 560 012, India rajanihf@gmail.com
2 Advanced Data Processing Research Institute (ADRIN), 203, Akbar Road, Tarbund, Manovikasnagar Post, Secundrabad 500 009, India. patra.sumant@gmail.com
3 Faculty of Geoinformatics, Indian Institute of Remote Sensing (IIRS), 4, Kalidas Road, Dehradun 248 001, India. mamta_iirs@yahoo.co.in

Key words: 3D perspective views, satellite image, remote sensing, Archaeology, Badami site.

ABSTRACT
Archaeological sites often exist as ruins. It is difficult to get an overall perspective while standing near them. The present work is a 3D visualization analysis conducted on the site of Badami which is in the state of Karnataka in India. The terrain of Badami is dramatically rocky. Scattered on this landscape are many Monuments that are either hewn from or built with the local rock, hence they appear camouflaged with the background or hidden because of the surface undulations. It is often difficult to spot individual structures from a distance. The peculiar topography of the site and its amenability for better understanding through 3D perspectives and synoptic coverage led us to carry out 3D visualization through virtual reconstruction of this landscape. Analyses of spatial distribution of monuments in this area together with slope, aspect and visibility analysis were conducted. Any construction around an archaeological site like roads, bridges and ropeways for access to the site or other construction in the surrounding area such as canals or factories can damage objects of historical significance and hinder the heritage value of the landscape. 3D terrain and building visualization and virtual flights can become a valuable tool for Cultural Resource Management for planning such construction activities without hindering the preservation of the site. Three different methods of generating 3D perspectives are discussed in this paper. Firstly 3D terrain generated from survey data, use of multidate satellite images of the site to create stereo pairs and thus generate 3D perspectives and thirdly use of direct stereo pairs of Indian CARTOSAT-1 satellite which has along track stereo capability.

1 INTRODUCTION:

Archeology, in common with all disciplines concerned with the interpretation of geographically located material, has witnessed an unprecedented transformation of methodological tools it uses for spatial records and analysis. Archaeologists have long been aware of the importance of the spatial component of the archaeological record. Recent technological advances that have made available digital maps, elevation models, and satellite images can prove to be new, powerful and attractive tool for studying archaeological landscapes. If integrated and visualized in an appropriate manner, these geo-coded data can project impelling impressions of the landscape under study. Virtual 3D models allows a landscape to be appreciated in much more detail than 2D maps due to the three dimensionality of the data layers. When a landscape is visualized in "real-time" and in an interactive mode, moving through a 3D model, different perspectives of the landscape are perceived (Sauerbier *et al*., 2006). Once a digital terrain model is prepared, it becomes a basis from which other thematic layers can be prepared such as slope map, aspect map, relief map and visibility map. They can become a starting point for a GIS-based analysis of spatial patterns and relations. If several data layers from different sources are combined, their scale or resolution or viewing angles may not cooperate, resulting in unsatisfying visualizations. Many virtual 3D models therefore represent a compromise between user requirements and available data.
Around AD 544, Pulakesin I founded the Chalukyan kingdom and his son established Vatapi, identified as Badami, as the capital. The selection of Badami as a capital was brilliant for political, strategic and aesthetic reasons. Two imposing sandstone cliffs dominate Badami. It formed a neutral protective wall for the capital of the Chalukyas. Embraced by the horseshoe-shaped curved cliff is a lake that supplied water. Badami town lies to the west of the lake beneath this precarious cliff. At sunset and sunrise one gets a view of the silhouette of the temples and rock-cut caves in the cliff. On the southern cliff is a stairway that leads to four exquisite rock-cut shrines carved into the rock-face. The first cave is for Siva; the next two for Vishnu, and the farthest is a Jain shrine (Harle, 1986).

2. DIGITAL ELEVATION MODELS

Digital Elevation Model (DEM) is used for extraction of terrain parameters such as elevation, slope, aspect, contour, drainage pattern. These parameters are often required in preparation of development and conservation plan for natural resources and infrastructure development. Three different methods of generating DEM are discussed here.

2.1 *DEM* ^{a}: In this we discuss a methodology adopted to generate DEM using the information on ground topography. Geopatial information generated from appropriate ground data of 20m intervals was used to genegrate DEM^{a} with 20m posting. Considering that the Badami landscape has a tank surrounded on three sides by steep cliffs: abrupt height differences got smoother due to height information limited to 20m interval and therefore the DEM had manually to be adjusted in the areas of steep height differences. The grey value in the DEM (*figure 1*) represents height variations (dark is lower elevation and white is higher).

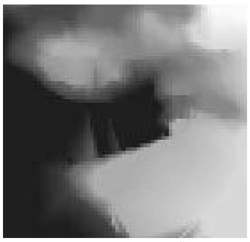


Figure 1. DEM ^{a}

Table 1. Data used for the study

Satellite/sensor	View angle	Spatial resolution	Swath	Date	H
IRS 1C PAN	+16.0°	5.8 m	70 km	10.03.00	817
IRS 1D PAN	+4.6°	5.8 m	70 km	18.01.02	817
Cartosat-1: Fore Aft	+26.0° -5°	2.5 m 2.5 m	30 km	13.11.07	617
IRS-P6 LISS-IV (Multispectral)	---	5.8 m	23 km	19.01.08	817

The other two DEMs (DEM^{b} and DEM^{c}) were prepared using stereoscopy. This principle is used to produce three-dimensional data from images taken from two locations, i.e. by observing the same area on ground from two points in space. In the resulting two images, due to the different views, any object in the second image will be displaced when compared to the first. This apprent shift caused by shift in the view angle is called parallax. From the stereo pair if the parallax difference (dp) between two points can be measured then the height of the object (h) can be calculated as dp divided by B/H ratio where B is the distance between two points of observation and H is the altitude of observation. The accuracy of height determination is dependent on the base to height ratio B/H. A B/H ratio greater than 0.5 is preferred for stereoscopic imaging because the accuracy of height determination improves as the B/H ratio increases (Joseph 2005). From a space based imaging system, stereo viewing can be achieved in different ways, categorized as across track stereoscopy and along track stereoscopy. Across track stereoscopy is achieved by using images taken from two adjecent orbits that have some common area (side lap), and along track stereoscopy by viewing at different view angles along the same orbit.

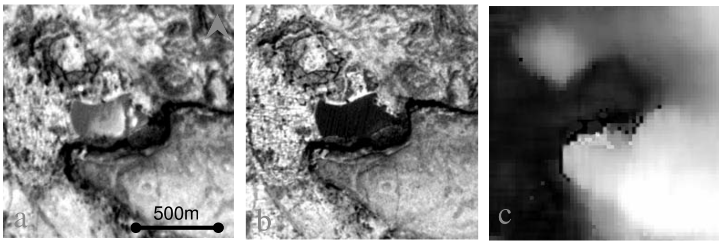


Figure 2. (a) IRS-1C image, (b) IRS-1D image and (c) the extracted 25m posting DEM ^{b} *from (a) and (b).*

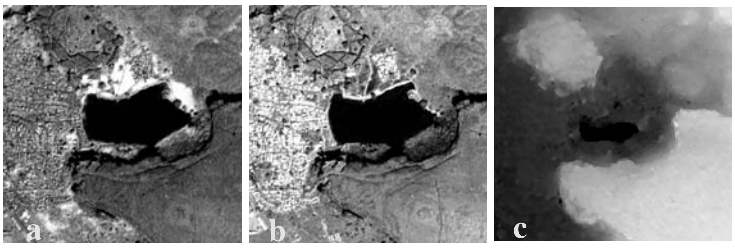


Figure 3. CARTOSAT-1 images: (a) Fore (b) Aft, and (c) extracted 5m posting DEM ^{c} *from (a) and (b).*

2.2 *DEM* ^{b}: was generated by using IRS-1C/1D. Indian Remote Sensing Satellites IRS-1C/1D carry on-board push broom Linear CCD PAN camera, providing high resolution stereo imagery of the earth's surface. DEM can be derived from PAN stereo pairs of IRS-1C or 1D or 1C/1D as a pair using suitable mathematical models. See Table 1 for sensor parametres. Thus by acquiring imagery over the same area from multiple orbits, a stereoscopic coverage can be obtained. As the images belong to two different sensors temporally, also with respect to geometry and radiometry, image correlation used for match point generation was not successful. It is not sensitive enough to represent the slight difference of the spectral characteristics in the stereo pairs. Mutual Information (MI) measures the amount of information that one image contains about another image by looking at their intensity distribution and usually produce a more sensitive results than correlation. Experiments show that the MI is better similarity metric than correlation in image fusion. We have employed this innovative technique of MI. Figure 2 shows IRS-1C/1D pairs and the extracted DEM ^{b} at 25m posting.

2.3 *DEM* ^{c}: was generated using data from CARTOSAT-1 which carries two state-of-the-art Panchromatic (PAN) cameras that take stereoscopic pictures of the earth (sensor parameters are listed in Table 1). The cameras are mounted on the satellite in such a way that near simultaneous imaging of the same area from two different angles is possible. This facilitates the generation of accurate three-dimensional maps. The CARTOSAT-1 image clearly depicts the location, extent, pattern and layout of Badami. *Figure 3* shows fore and aft image pairs and the extracted DEM ^{c} at 5m posting.

3 DEM COMPARISON

The three approaches of DEM generation i.e. DEM^a, DEM^b and DEM^c were compared qualitatively and quantitatively. Our first observation was that the sharp delineation of topographical features was not possible in DEM^a because of the smoothing effect due to limitations of using 20m interval. The pair of IRS-1C/1D being multi-sensor and multi-temporal gas its own limitations with respect to geometry, radiometry and noise. CARTOSAT-1 being stereo imaging by design avoids the above limitations and is capable of generating a reliable DEM.

4 PANSHARPENED NATURAL COLOUR

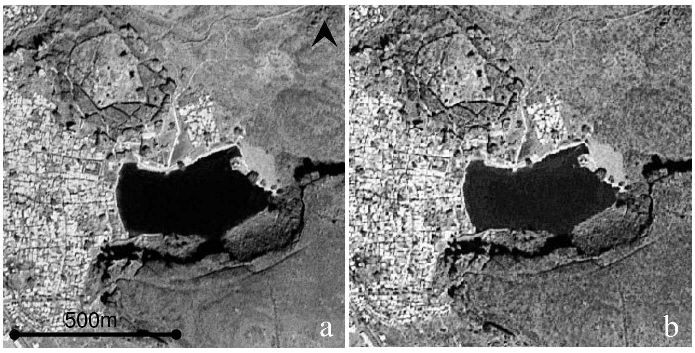


Figure 4. Illustrates Pansharpened images of the site of Badami. (a) False color composite, (b) Natural color.

For a better colour rendition of the terrain surface we have also examined the effect of pansharpened “natural colour” image of the site for draping over DEM. The pansharpening algorithm 'fuses' the high-resolution panchromatic and lower-resolution multispectral imagery to create a higher-resolution colour image. The high-resolution color image preserves the original colour fidelity and allows for better visualization and interpretation. For visualisation pansharpened image was generated using IRS-P6 LISS-4 data and CARTOSAT-1 orthoimage. The lower spatial resolution multispectral image of IRS-P6 LISS4 is first registered to a higher spatial resolution PAN image of CARTOSAT-1 AFT image which is near nadir. Next, the registered multispectral image is merged with the PAN image producing a multispectral image with higher spatial resolution. This merging process usually involves transforming the multispectral bands from the original multispectral band space into an alternative transform space. Image transformations retain all of the information present in the original multispectral bands and the transformed data is often more interpretable than the original data. Once the multispectral bands have been transformed into a transform space, the higher resolution PAN image is replaced with the first transform band and the data is transformed back to original multispectral band space to yield the pan-sharpened multispectral data. As ISR-P6 does not have a blue channel, a true colour could not form. A blue band was simulated using a natural colour generator (Patra, 2006) and a pansharpened natural colour was prepared. Figure 4 shows the generated pansharpened false colour and natural colour images. Vegetation looks red in FCC as in figure 4(a), whereas it is naturally green as shown in figure 4(b).

5 VISUALIZATION

The forgoing steps enable us to to achive 3D visualization and virtual reconstruction of landscape and monuments of Badami. Generated natural colour image of figure 4(b) was draped on the generated DEM^c of CARTOSAT-1 shown in figure 3(c).

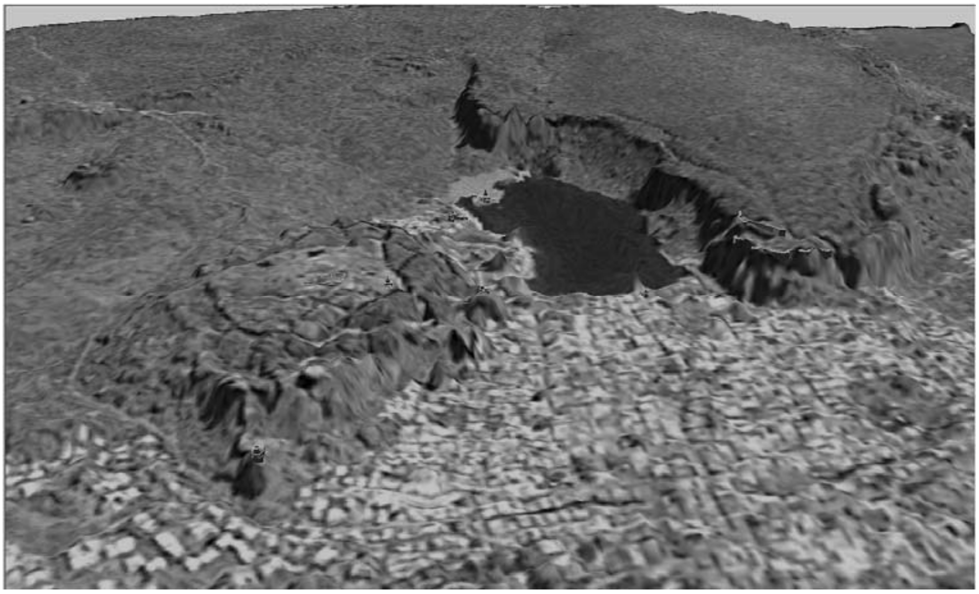


Figure 5. 3D perspective view distribution of monuments in Badami

Figure 5 illustrates the visualization. A vector layer was prepared with polygons of the archaeological buildings (orange colour) with height attributes on ERDAS software, Virtual GIS Module. This led to creating persepective views of the landsacpe and virtual Fly-through over Badami. Slope, aspect and relief maps and map showing monuments were prepared. A visibility map was also prepared using Virtual GIS module in ERDAS. Using the visibility analysis, the areas that are hidden from monuments within a given radius can be identified. This analysis can be used to identify areas for modern activity such as tourist development or car parks, which can be near the sites but still out of view from the sites themselves, therefore preserving heritage value of the scene around monuments. Figure 6 shows visibility analysis of 350m radius around monuments. The coloured regions within red circles are visible from monuments.

6 CONCLUSION

This exercise has illustrated that Archaeological sites can be viewed synoptically in 3D through space borne imaging. It gives a better understanding of the spatial extent of the site. This exercise has made possible to make viewshed, slope and aspect maps of the study area. 3D terrain and building visualization and virtual flights can become a valuable tool for Cultural Resource Management in planning construction activities like that of roads, bridges and ropeways for access to the site or other construction in the surrounding area such as canals or factories without devaluing the heritage site.

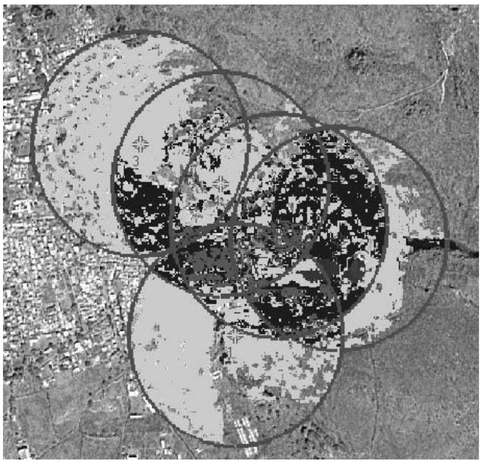


Figure 6. Visibility for radius of 350m around the monuments.

REFERENCES:

Harle, J.C. 1986. *Art and architecture of the Indian subcontinent*, The Pelican History of Art, Penguin Books, re-printed by 1990.

Joseph, George 2005. *Fundamentals of remote sensing* University Press, Hyderabad, India.

Sauerbier, M., Schrotter, G., Lambers, K., Eisenbeiss, H. 2006. Multi-Resolution Image-based Visualization of Archaeological Landscapes in Palpa, Peru, In: *From Space To Place - 2nd International Conference on Remote Sensing in Archaeology*, Proc. of the 2nd Int. Workshop, Eds.: Stefano Campana, Maurizio Forte. BAR International Series 1568, Archaeopress, Oxford, pp. 353-359.

Patra, S. K. et al., 2006. A Technique for Generating Natural Colour Images from False Colour Composite Images', *International Journal of Remote Sensing*, 27(14):2977–2989.

ACKNOWLEDGEMENTS

We thank Dr. K. Kasturirangan, Director, NIAS, Dr. R.Krishnan, Director, ADRIN, and Dr. V.K.Dadhwal, Director, IIRS, for their overall guidance, Institutional support and encouragement in carrying out the present study. We thank Prof. B.V. Sreekantan and Prof. M.S. Krishna Murthy at NIAS for useful discussions. We also thank Regional Remote Sensing Service Centre, Bangalore, for providing Lab facility for few of the presented analysis.

7

Remote Sensing and GIS based method applications for the Cultural Heritage Management and Documentation

NASA remote sensing applications for archaeology and cultural resources management.

M. J. Giardino
NASA Stennis Space Center, Mississippi, USA. E-mail: Marco.J.Giardino@nasa.gov

ABSTRACT

The NASA Stennis Space Center, located in Mississippi, USA has conducted archaeological research from aerial platforms using both multispectral and hyperspectral sensors since the mid-1970s. Initially targeted at broad archaeological issues, Stennis' airborne archaeology has progressed toward developing practical applications for cultural resources management. NASA's archaeological imagery builds on traditional methods of aerial archaeology (i.e. crop marks; shadow marks) and utilizes advanced technologies for collecting and analyzing archaeological data from digital imagery. Remote sensing research has been conducted on archaeological sites located throughout North and Central America, including prehistoric mound sites and historic settlements in Mississippi; prehistoric shell middens in Louisiana; Olmec and Mayan sites in Mexico, and archaeological sites associated with the Lewis and Clark Corps of Discovery Expedition (1804-1806). The relevant imagery was collected with multispectral radiometers including the Airborne Terrestrial Applications Sensor (ATLAS) and with hyperspectral sensors like the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and the Coastal Research Imaging Spectrometer (CRIS). Innovative data processing techniques including data fusion, linear spectral unmixing, match filtering, end member identification; plant stress algorithms; historic vector overlay and advanced data visualization techniques are developed with the goal of making them practical for easy use by the archaeological community. NASA's remote sensing for archaeology programs provide cost-effective applications for the discovery, mapping and analysis of archaeological sites and their surroundings.

Keywords: Multispectral, ATLAS, hyperspectral, AVIRIS, CRIS.

NASA's Earth Science Mission Directorate recently completed the deployment of the Earth Observation System (EOS) which is a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. One of the many applications derived from EOS is the advancement of archaeological research and applications. Using satellites, manned and unmanned airborne platform, NASA scientists and their partners have conducted archaeological research using both active and passive sensors. The NASA Stennis Space Center (SSC) located in south Mississippi, near New Orleans, has been a pioneer in "space archaeology" since the mid-1970s.

Remote sensing is useful in a wide range of archaeological research applications from landscape classification and predictive modeling to site discovery and mapping. Remote sensing technology and image analysis are currently undergoing a profound shift in emphasis from broad classification to detection, identification and condition of specific materials, both organic and inorganic. In the last few years, remote sensing platforms have grown increasingly capable and sophisticated. Sensors currently in use, including commercial instruments, offer significantly improved spatial and spectral resolutions. Paired with new techniques of image analysis, this technology provides for the direct detection of archaeological sites.

As in all archaeological research, the application of remote sensing to archaeology requires a priori development of specific research designs and objectives. Remote sensing is not always applicable to all archaeological work. Clear and specific research designs and objectives will greatly enhance the utility of remote sensing in archeology, leading to the proper identification of the sensors and wavelengths required to provide the proper spatial, spectral and radiometric resolutions.

Initially targeted at broad archaeological issues, NASA space archaeology has progressed toward developing practical applications for cultural resources management (CRM). These efforts culminated with the Biloxi Workshop held by NASA and the University of Mississippi in 2002 (Johnson, 2006). The workshop and resulting publication specifically address the requirements of cultural resource managers through the use of remote sensing. In 2007, NASA awarded six competitively chosen projects in Space Archaeology through an open solicitation whose purpose, among several, was to addresses the potential benefits to modern society that can be derived through a better understanding of how past cultures succeeded or failed to adapt to local, regional, and global change. A further objective of NASA's space archaeology is the protection and preservation of cultural heritage sites while planning for the sustainable development of cultural resources.

NASA's archaeological research and application projects using remote sensing have been conducted throughout the world. In North America, NASA has imaged prehistoric mound sites in Mississippi; prehistoric shell middens and mounds in Louisiana including Marksville and Poverty Point, Puebloan sites in New Mexico like Chaco Canyon and more recently the sites associated with the Lewis and Clark Corps of Discovery Expedition (1804-1806). In Central America, NASA archaeologists have researched Mayan sites throughout the region, including the Yucatan and Costa Rica, as well as Olmec localities in Veracruz. Other NASA data has been collected over Angkor, Cambodia, Giza in Egypt and the lost city of Ubar on the Arabian Peninsula.

NASA's archaeological approach through remote sensing builds on traditional methods of aerial archaeology (i.e. crop marks) and utilizes advanced technologies for collecting and analyzing archaeological data from digital imagery (cf. Lasaponara & Masini, 2007; Aqdus *et al.*, 2007; Spruce & Giardino, 2002). Hyperspectral sensors increase the potential for identifying plant species, as well as plant vigor (or lack thereof). Research indicates that variations in plant health can be detected in vegetation reflectance curves in specific regions of the red and near infrared regions of the electromagnetic spectrum (EMS) (Carter *et al.*, 1996). It is possible that plants growing on organically enriched midden soils grow more vigorously than those on "sterile" soil.

In the salt marshes of Gulf of Mexico, large Rangia shell middens are covered with marsh grass and other vegetation (Eleuterius & Otvos, 1979). Hyperspectral imagery collected over several shell middens and covered by single specie of plant (i.e., Spartina sp.) is employed to determine whether plants growing on these sites differ from those located off the site by either flourishing more vigorously due to the increased organic content, or not developing as well due to the hard substrate. It is, therefore, possible to associate spectral variability in a homogenous plant stands like Spartina with the nature of the substrate. More research is on-going, but if these conditions can be resolved spectrally, the geologic and pedological characteristics of large regions can be examined using classification algorithms and digital processing and vegetation analogues (Jones & Giardino, 1997).

A particularly useful methodology for CRM employed by researchers at the Stennis Space Center involves georeferencing and co-registering old maps and plats to modern high spatial resolution imagery (Giardino & Thomas, 2002). Multispectral and hyperspectral data collected from orbiting and airborne platforms is co-registered to digitized historic plats and maps. This approach, besides providing more precise locations of historic sites and features, produces very accurate site maps, particularly when the data are registered to active sensors like LIDARs and RADARs. Digital Elevation Models (DEMs) developed with the use of active sensors, are utilized in combination with X and Y coordinates derived from high spatial resolution imagery to produce accurate 3-D renderings of sites and the surrounding environment.

This modeling method was applied to the Lewis and Clark expedition bicentennial project (Karsmizki *et al.*, 2002). Dr. Ken Karsmizki of the Columbia Gorge Discovery Center in Oregon provided NASA with copies of the original Clark maps and with a prioritized list of research objectives. Remote sensing scientists at Stennis Space Center then enhanced satellite imagery (initially LANDSAT and AVHRR) with elevation models to project the historic Lewis and Clark maps onto the current topography. William Clark produced the vast majority of the maps collected during the Corps of Discovery Expedition. Since Clark often denoted the location of bluffs on his charts, the elevation models served to refine the prediction of site locations. While the rivers that the Corps of Discovery navigated have often changed course over the last 200 years, the bluffs have remained mostly stable. Using this approach, NASA forwarded to archaeologists the predicted locations for such important sites as Fort Clatsop and Fort Mandan. Co-registration of modern images with his historic maps, including the renderings of bluffs and other elevations, narrows the search for related historic localities, thus saving time, lessening subsoil disturbance and avoiding excessive transit through private lands.

NASA's development of more accurate co-registration algorithms is being refined at the site of Gainesville, Mississippi, county seat of Hancock County during the mid-19th century. Gainesville was one of five historic towns that became part of the NASA Stennis Space Center Buffer Zone and Fee area in 1962 with the advent of the Saturn rocket program that launched the Apollo spacecrafts to the Moon. Gainesville, nominated to the National Register of Historic Places, is being studied and preserved through use of a wide range of remote sensing techniques. In essence, NASA is developing the Gainesville site as an archaeological validation and verification site for the application of a variety of remote sensing data collection and interpretation methods. Data collected over this site include high spatial resolution multispectral data from IKONOS and Quick Bird; multispectral data including thermal from the NASA ATLAS airborne sensor; geophysical data including ground penetrating radar, magnetometry and resistivity; LIDAR and airborne RADAR data and hyperspectral data from an airborne platform and digital photography from small blimps. Each section of the Gainesville site has been defined by overlying a grid over an image whose resolution is less than one meter. The grid, aligned and denoted by UTM coordinates is replicated in the field. All field results are then easily fused using the UTM grid as the baseline. In this way, anomalies are more easily interpreted. Scientific excavations provide the final validation and verification of remotely sensed signals.

All remote sensing approaches, including geophysical prospecting methods, are then fused into single images. These images are eventually rendered into 3D visualizations which enable the researchers to virtually penetrate the subsoil and explore the data in three dimensions. In addition, the correlation of digital signals between the many sensors provides important baseline data on the utility of each in identifying specific types of deposits, both natural and cultural. In his way, the most efficient and effective technology for various aspects of archaeological research and applications is identified and the information is provided to CRM firms, and conservation agencies for specific, practical use without costly expenditures of resources. A properly designed and implemented remote sensing approach to CRM offers the potential to save nearly 60% of the costs of traditional surveys.

NASA scientists continue to contribute significantly to a wide range of Earth Science topics, including archaeology. From the low to moderate spatial resolution of orbiting sensors to the high spatial and spectral resolutions of digital imagery taken from airplanes and UAVs, NASA provides archaeologists with information products useful in a wide range of archaeological research. Space archaeology provides the opportunity to conduct substantive research and applications with minimum disturbance to archaeological sites and deposits while resulting in significant cost savings to the various projects. .

REFERENCES

Aqdus, S. A., Hanson, W. S., Drummond, J. 2007, A comparative study of finding archaeological cropmarks using airborne hyperspectral, multi-spectral and digital photographic data, *RSPSoc Annual conference proceedings 2007.*

Carter, G. A., Cibula, W. G., Miller, R. L. 1996. Narrow-band reflectance imagery compared with thermal imagery for early detection of plant stress. *Journal of Plant Physiology* 148:516-523.

Eleuterius, L. N., Otvos, E. 1979. Floristic and geologic aspects in salt marshes of Hancock County, Mississippi. *Sida* 8: 102-112.

Giardino, M., Thomas, M. 2002. NASA Remote Sensing Research as Applied to Archaeology. *The SAA Archaeological Record*, 2 (3) :15-19.

Johnson, J. (editor) 2006. *Remote Sensing in Archaeology: An Explicitly North American Perspective.* Tuscaloosa: University of Alabama Press.

Karsmizki, K.W., Spruce, J., Giardino, M. 2002. Archaeological Remote Sensing: Searching for Fort Clatsop from Space. *NASA Technical Report SE-2002-07-00054-SSC*

Lasaponara, R., Masini, N. 2007. Detection of archaeological crop marks by using satellite QuickBird, *Journal of Archaeological Science*, 34: 214-221.

Spruce, J.P.; Giardino, M. 2002. Use of IKONOS Data for Mapping Cultural Resources of Stennis Space Center, Mississippi. *NASA Technical Report 2005-08-25 SE-2002-02-00011-SSC.*

Archaeological heritage management through aerial photography and satellite imagery: the Uch Enmek park – Republic Altay, Russia

W. Gheyle[1], R. Goossens[1], A. De Wulf[1], E. P. Dvornikov[2], J. Bourgeois1

1 Univeristy of Ghent, Department of Archaeology, Blandijnberg 2, and Department of Geography, Krijgslaan 281, S8, B-9000 GENT, Belgium, email: Wouter.Gheyle@ugent.be, Rudi.Goossens@ugent.be, Alain.DeWulf@ugent.be, Jean.Bourgeois@ugent.be

2 Gorno-Altaisk State University, Lenkin str. 1, Gorno-Altaisk, Altai Republic, Russian Federation, email: Kae@gasu.ru.

Keywords: Aerial photography, CORONA imagery, archaeological maps, Scythian archaeology

ABSTRACT.

The Altay Mountains (Russia, but also China, Kazakhstan and Mongolia) are well known for their rich archaeological heritage. Especially the thousands of Scythian kurgans (burial mounds) make this area one of the richest archaeological areas in the world. In addition, the area is dotted with many older and younger monuments. The oldest monuments date back to the Neolithic, while later monuments include Turkic and Mongolian remnants. Some of the Scythian burials are frozen, as a result of climatic conditions typical of these high mountain areas. This allowed for the conservation of all organic remains: wooden objects, textiles, leather and felt, and even the bodies of people and horses. The splendid burials of Pazyryk or Ukok are well known. These remains undoubtedly deserve to be part of the world cultural heritage.

However, the frozen tombs are threatened by global warming, and risk to disappear. In recent years, archaeologists from various countries (Russia, China, Mongolia, Kazakhstan, but also Germany, Belgium, France, USA) joined forces to develop a methodology that would preserve some of these graves. Moreover, the intensification of tourism is a new threat, as the grip of the man becomes more and more pressing in the area.

In this race against time, the need to produce archaeological maps at acceptable scales is critical: the management of the archaeological heritage cannot be done effectively without the help of good, comprehensive and sufficiently detailed archaeological maps.

The Department of Archaeology and the Department of Geography at Ghent University has developed a methodology to produce topographic maps (scale 1/25.000) from satellite images, including CORONA images. In addition, for the archaeological inventory, a method was developed for mapping and describing of all the visible archaeological monuments to site plans at 1 200.

During the 2007 campaign, archaeological work has concentrated in the valley of Karakol (Republic of Altay), which is part of the natural park of Uch Enmek. More than 500 archaeological monuments have been surveyed, described and identified in a region roughly covering the central part of the valley of Karakol.

In addition, an aerial survey has been completed. The archaeological air survey has resulted in many images of the well visible monuments, but it mainly offered the advantage of showing the sites in a broader context. Finally, a photogrammetric flight was conducted on part of the Bashadar burial place.

This paper will present the methodology of mapping archaeological heritage, as well as the results obtained during the fieldwork in the valley of Karakol. The results of aerial surveys as well as photogrammetric recording will also be presented.

1. INTRODUCTION

Ghent University has a long tradition of archaeological research in the Altay Republic, from 1995 on (Bourgeois *et al.*, 2000; Bourgeois & Bourgeois, 2006). After some years, we decided to focus our fieldwork on surveying rather than on excavating. Several valleys in the Chuya Steppe (Altay) were mapped in 2003 and 2004. The presentation of this work and some consecutive meetings with UNESCO yielded in a project funded by the UNESCO/Flanders Fund-in-Trust for 2005 and 2006 (Bourgeois & Gheyle, 2006; Han, 2008). The main goal of this project is the preservation and conservation of the frozen tombs of the Scythian culture, that lie scattered in the Altay Mountains across Russia, Kazakhstan, Mongolia and China.

These ancient Scythian tombs, so-called *kurgans*, contain outstanding cultural relics and the unique remains of the Scythian civilization. The frozen condition of some of the graves has permitted the conservation of all organic materials, including the mummified body of the deceased, sacrificed horses, harnesses, saddles, furniture, textiles, and carpets, etc. However, these relics are now endangered by various factors, including a lack of knowledge about how many such tombs exist and their exact location and description, as well as global warming, which is melting the permafrost that has guaranteed their preservation over the millennia (Bourgeois *et al.*, 2007).

Although the ultimate objective of the project will be the preservation of the frozen tombs, taking into account the enormous size of the region and the scale of the work involved, the project activities will be carried out on a step-by-step, phase-by-phase basis. Therefore, the first phase of the projectconcerned the accurate mapping of two research areas in the Russian and Kazakh part of the Altay Mountains (Dzhazator, Kara-Kaba, Bukhtarma and the site of Berel).

In 2006, a new project started, funded by a Bilateral scientific cooperation between Flanders and the Russian Federation (Research Council, Ghent University): “A reflection of the world in the landscape. Aspects of ritual and funerary practices of the ancient people of the Sayan-Altay region”. The first field campaign within this project was executed in 2006. The goal of the fieldwork within the Bilateral Cooperation was to finish the inventory of the very rich Yustyd Valley (Kosh-Agatch region), that was initiated during the expedition of 2004.

The second campaign in 2007, took place in the Valley of the Karakol River. The Karakol Valley is part of the Ethno-Natural Park “Uch Enmek”, and contains a few of the most famous Scythian burial sites in Altay. Archaeologist S.I. Rudenko excavated in 1950 two big burial mounds on the site of Bashadar, and found perfectly preserved burials with magnificent finds, conserved in the permafrost (Rudenko). The park also covers the very rich site of Tuekta, along the Ursyl River (Rudenko). Next to these big sites, there are thousands of smaller monuments, spread over the total area of the park (about 40 km long and 15 km wide).

The valley is dominated by the centrally located “Uch Enmek” mountain, that is believed to be the ‘navel of the Earth’, connecting our world with the world of the spirits and the cosmos in general. The nature itself, but also the archaeological heritage, is therefore considered to be sacred. Many of the burial mounds have been dug up long ago, and the staff of the park wants to avoid future destruction, by tourists or by unnecessary excavations.

2. RESULTS OF THE ARCHAEOLOGICAL SURVEY

The Department of Archaeology and the Department of Geography at Ghent University have developed a methodology to produce topographic maps (scale 1/25.000) from satellite images, including CORONA images. In addition, for the archaeological inventory, a method was set up for mapping and describing of all the visible archaeological monuments to site plans at 1/200 (Goossens *et al.*, 2006). All information was stored in an Access database that is linked with a GIS platform in ArcMap.

In total, 1248 different structures were located and described, spread over 66 archaeological sites. The structures belong to different periods ranging from the Bronze Age (Afanashevo culture) and the Iron Age (with the Scythian monuments) to the ethnographical period (18th-20th century CE). Different types of structures were recorded, from large burial mounds to small standing stones. In 236 cases, it was not possible to define the chronological attribution of the monuments.

The oldest recorded structures date back to the late Bronze Age (roughly 2nd mill. BCE), but only 10 structures are attributed to this period. This is strange: the absence of Late Neolithic and big Bronze Age monuments in the research areas is striking. Especially the absence of the very well known *khereksurs* is peculiar. These big structures, consisting of a quite large and high central mound, enclosed by a circular or quadrangular bank, are numerous in the Kosh-Agatch region (Russia) and in the Mongolian Altay. Large concentrations of big *kereksurs* dominate parts of the valleys and steppes in those regions. The 10 structures dating from the Bronze Age are possibly belonging to the Afanashevo culture. The sites are all burial monuments, consisting of a round or oval setting of large stones, with a central grave, mostly rectangular.

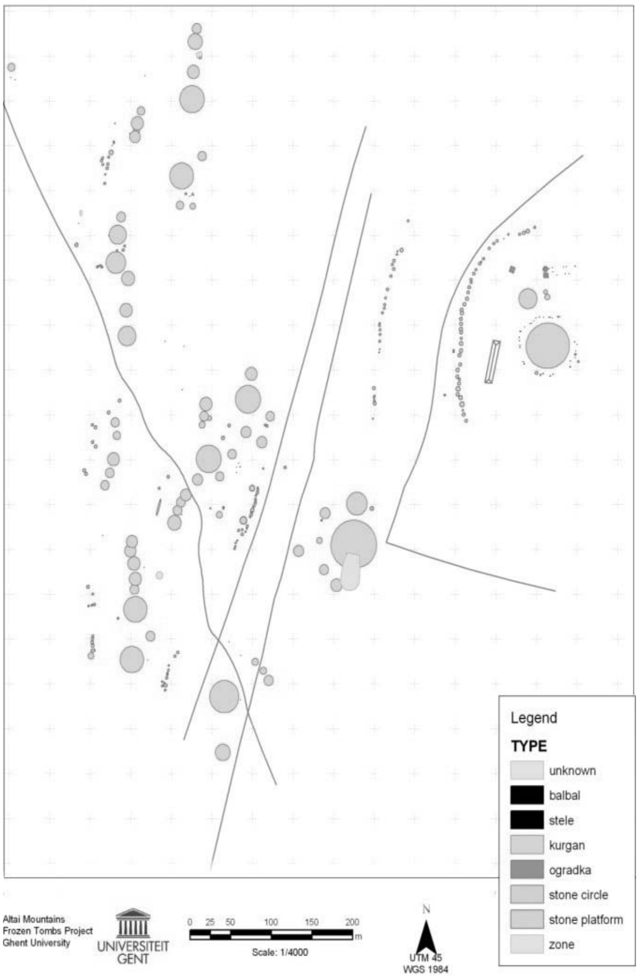


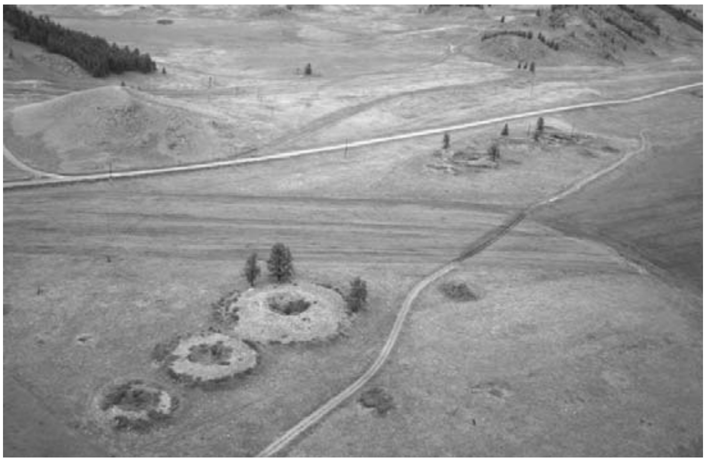
Figure 1. Site plan of the Bashadar burial place and surrounding monuments, result of the 2007 fieldwork

We recorded 874 structures dating to the Scythian period (9th-4th century BCE), making it the largest category of monuments (70%). Among these, the Scythian graveyards with *kurgans* (burial mounds) are maybe the easiest monuments to discover and record. The kurgans typically have a diameter varying from 5 to 15 meter and are characterised by the presence of a central depression, due to the collapse of the burial chamber and/or robbing. In the Karakol Valley however, numerous *kurgans* are much larger. On the site of Bashadar, for instance, some of the largest kurgans have a diameter of up to 40-50 meter (figure 1). The cemeteries are generally surrounded by standing stones in the East and stone circles or small stone concentrations (stone platforms) in the West. It was sometimes difficult to find these smaller side structures due to long grasses and pasture land. But nevertheless, 238 standing stones or *balbals*, 336 stone circles and 68 stone platforms were recorded. More recent structures include structures from the Hunno-Sarmatian and Turkic period (3rd century BCE to 9th century CE). Hunno-Sarmatian monuments are well known in some regions of the Russian Altay Mountains, where archaeologists found extensive graveyards with hundreds of relatively small, oval shaped burial mounds (2x1m, 3x2m etc.). In Karakol however, the only burial place of this kind consisted of 26, rather unclear graves. The Turkish period is not very well presented in the research area. Only 81 monuments of this period were found.

3. AERIAL SURVEY

An aerial survey of the whole valley was done with a motorized delta plane. The purpose of this flight was double:

- The first goal was to do an archaeological survey of the whole valley. For this purpose, the photographer used a digital Canon EOS D300 camera with 22-55mm lens. In total, about 600 photos were shot over the whole area, covering most of the archaeological sites.



•*Figure 2. Aerial photo of a Scythian burial site in the valley of Karakol*

- The second plan was to make a digital elevation model of site ON-022, one of the biggest sites, by taking stereoscopic images and using photogrammetrical techniques. The preferred flight height and focus length was calculated, and a Canon EOS D300 camera with fixed 25mm lens was used to take the images, both in RAW and high quality JPEG. Before the flight, we installed 40 Ground Control Points on the site, marked by quadrangular, white boards (50x50cm) with a black square in the centre. Their position was measured with a differential GPS receiver (C-Nav, C&C Technologies) with a precision of 12 cm (figure 3)

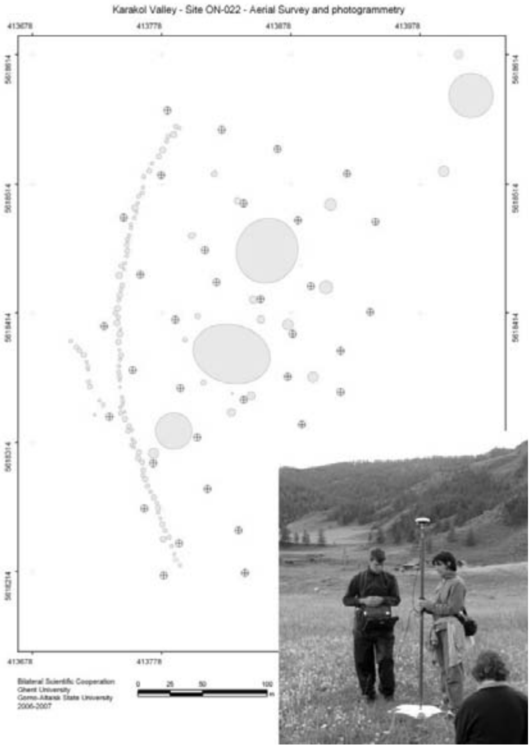

Karakol Valley - Site ON-022 - Aerial Survey and photogrammetry
413678
413778
413878
413978
5618614
5618514
5618414
5618314
5618214
Bilateral Scientific Cooperation
Ghent University
Gorno-Altaisk State University
2006-2007
0
25
50
100
m

Figure 3. Location of GCPs on the covered area (burial mounds and side structures in green) and measurements with the C-Nav differential GPS receiver

The survey flight was a success, and gives us very good additional documentation of the sites in the area. The data from the photogrammetrical coverage of site ON-022 have been processed at the Department of Geography.

4. REFERENCES

Bourgeois, I., Cammaert, L., Massart, Cl., Mikkelsen, J.H., Van Heule, W. 2000. *Ancient Nomads of the Altai Mountains. Belgian-Russian Multidisciplinary Archaeological Research on the Scytho-Siberian Culture*, Brussels, Royal Museums of Art and History.

Bourgeois, I., Bourgeois, J. 2006. Unexplored valleys, potential frozen kurgans and heritage management. Belgian archaeological research in the Altai Republic (Russian Federation): survey and inventory 1996-2000, in *Papers of the XIVth UISPP congress on Archaeology, British Archaeological Reports, International Series, 1523*, 17-24.

Bourgeois, J., De Wulf, A., Goossens, R., Gheyle, W. 2007. Saving the frozen Scythian tombs of the Altai Mountains (Central Asia)., in: Cooney, G. (ed.) *The Archaeology of World Heritage, World Archaeology*, 39, 3: 458-474.

Bourgeois, J., Gheyle, W. (eds.) 2006. *The Frozen Tombs of the Altai Mountains*, Ghent, Ghent University UNESCO.

Goossens, R., Dewulf, A., Bourgeois, J., Gheyle, W., Willems, T. 2006. Satellite imagery and archaeology, the Example of CORONA in the Altai Mountains, *Journal of Archaeological Science*, 33: 745-755.

Han, J. (ed.) 2008. *Preservation of the Frozen Tombs of the Altai Mountains*, Paris, UNESCO.

Rudenko, S.I. – Руденко, С.И. 1960. Культура населения Централного Алтая в Скифское время, Москва/Ленинград, Изд. Академии Наук СССР

Remote Sensing and GIS for Archaeological Site Selection: Indian Examples

Asis Bhattacharya
Department of Geology, Presidency College, Kolkata, India

Keywords Remote Sensing, GIS, Palaeochannels, Quaternary.

ABSTRACT.

Archaeological studies with respect to Remote Sensing (RS) and Geographical Information System (GIS) aim to target the locales or to get the clues where the remains of historic and pre-historic ages can be found out to establish an archaeological event, or more specifically a civilization or a continuity of a civilization. In the present paper, the objective is to focus on the integration of RS and GIS in archaeology, citing Indian examples, such as Satvahana Dynasty (30 BC - 3rd Century AD) in Kondapur of Andhra Pradesh state, India and civilizations of various historical periods as located in various palaeochannels in West Bengal, Orissa and Tamil Nadu states of India. RS & GIS techniques have immense applications in the field of archaeology, though in India, its use is very limited. Details are elaborated in the coming sections

• 1. INTRODUCTION

Apart from the grammatical definition, for all the practical purposes, by Remote Sensing (RS), we mean analysis of images and digital data, acquired in the different wave length regions of Electro Magnetic Spectrum (EMS), through some specific sensors on board series of satellites, for various natural resources surveys, monitoring and management including archaeological studies. Geographical Information System (GIS) is a geo-referenced data base creation in layered sequences of various themes, and integrating them for desired model development. GIS is a computerised mapping system capable of capturing, storing, retrieving, analysing /querying and displaying. It geo-references spatial & non-spatial data. Practitioners also regard GIS as a system comprising hardware, software, operating personnel and the data that go into the system.

The Late Quaternary period or more specifically the Holocene period is very important for archaeological studies, because the human race appeared on the earth's scene during that period, and civilization started spreading. All Palaeolithic, Neolithic, Chalcolithic and other historic and pre-historic remains are found during this period. Hence, it was my concept as how to identify such sites using Remote Sensing data.

• 2. RATIONALE FOR USING RS DATA

In India, during the early civilization, the trade paths were all along the river channels and sea routes. Hence, I tried to use the satellite data in order to establish the early civilization along the palaeochannels of the different present-day river courses, as well as beach ridges in coastal plain. As the Quaternary deltaic plains were evolved through various off-lap sequences of delta building processes, certain image interpretation keys are developed. Same is in the case of erosional landforms in Archaean-Proterozoic terrain.

• 3. REMOTE SENSING AND GIS FOR ARCHAEOLOGY

It gives perspective of the terrain with geographic reference.

RS data gives a clue for the potential archaeological landforms like palaeochannels, levees, ancient each ridges, etc in the Quaternary alluvial plains.

It also indicates undulating plains, low mounds and water bodies in the Quaternary erosional surfaces of pediment and buried pediment.

From RS data, climatic condition and processes to geomorphic evolution can be understood.

Thematic Layers concept for decision and modeling using GIS can be carried out.

- 4. STUDY AREA

  Parts of alluvial terrains of Andhra Pradesh, Assam, Orissa, Tamil Nadu, Uttar Pradesh and West Bengal States in India
  Quaternary pedogenetic plain over pediment in granitic terrain at Kondapur, Andhra Pradesh

- *4.1 Characteristics of Quaternary Plain*
  1. Vast Alluvial Plain is related to eustatic processes.
  2. Pedogenetic Plain over pediments and pediplains is related to denudational processes

- *4.2 Relation between Archaeology and Quaternary Period*
  1. Human evolution took place during Quaternary period.
  2. Human civilization flourished during Late Quaternary period or Holocene.
  3. Civilizations are mainly River basin based, Shore based and Foot-hill based.

- *4.3 Data Used (Quaternary Alluvial Plain)*

  1.IRS 1C/1D, P6 and AWiFS FCCs and digital data, 2.SOI Toposheets, 3.Ground truth data, and 4.Contextual Archaeological data and relevant literature

- *4.5 Methodology*

  1.Image Enhancemen (Sabins, 1978), 2.Image Analysis and Interpretation, 3.Geomorphic Analysis, and 4.Data Integration through GIS for potential Archaeological site identification

- *4.6 Interpretation Keys in Quarternary Plain*
  1. Deltaic off-lap sequences
  2. Proximity of the palaeochannels
  3. Superimposition of the palaeochannels
  4. Obscurity of the palaeochannels
  5. Preservation of landforms

- *4.7 Results (Quaternary Terrain)*

Following the methodology and using the interpretation keys, the civilisations of Sen Dynasty (9th – 11th Century AD) equivalent period are found in the palaeochannels of South 24 Parganas of West Bengal, (Fig.1) the Kalapahar regime (14th Century AD) in the Chandbali region palaeochannels of Baitarani-Brahmani valley in Orissa and Chola Dynasty (9th – 13th Century AD) in the palaeochannels of Penar-Palar rivers of Tamilnadu (Bhattacharya, 2007).

- 5. LOCATION OF KONDAPUR SITE

(Pedogenetic Plain over pediments)
60 km WNW of Hyderabad City near Kondapur village, Medak district, Andhra Pradesh

- *5.1 Objective*
  1. Locating new Archaeological Sites using knowledge from existing sites
  2. Demonstrating the use of GIS and Remote Sensing Techniques for such exploration work

- *5.2 Tools*
  1. IRS-IC PAN data with Spatial Resolution of 5.8 meters
  2. Toposheet on 1:50000 scale
  3. Field information of known sites(Archaeological Survey of India)
  4. Erdas Imagine 8.2 and Arc/Info software
  5. DEC Alpha Work Station

- *5.3 About Kondapur Study Area*
  1. Located near to large water body
  2. Middle Stone Age Archaeological find discovered as low mound
  3. Old township of Satavahanas
  4. Stone Age factory for tools
  5. First explored in 1900

- *5.4 Methodology*

As palaeochannels are very important locales in the Qurternary deltaic plains and terraces for archaeological findings, equally the undulating plains, low mounds and water bodies are very important in the Quaternary erosional geomorphic surfaces of pediment and buried pediment regions in the various terrains of Archaean and Proterozoic geological ages. In Kondapur of Andhra Pradesh, there are various surface ruins or indications such as potteries are found in certain pedimented geomorphic surfaces overlying Peninsular granitic gneisses. When field work was carried out along with the Archaeological Survey of India, Hyderabad, we found some remains of Satvahana period in one of those potential locales. Hence, we developed a method as below:

1. Generation of thematic layers like geomorphology (landforms), surface water bodies, route connectivity, mounds and habitation.
2. Integration of all the thematic layers in GIS environment to develop a model for locating other potential locales.
3. Extracting information and deriving suitable weights from known site, and exploring for the unknown sites.

- *5.5 Results (Kondapur area)*

1. Five probability index (Fig.2) were derived with highest probability getting Index one. These zones are the most probable zones for new sites.
2. The lowest probability zone five is in the shallow buried pediment where the chance of locating new sites is less.
3. The areas of high probable zones for archaeological sites with high probability index are suggested for future exploration work

- 6. CONCLUSION

1. Cost effective and timely technology for massive exploration programme.
2. The total cost of the Kondapur project covering 50 by 50 Sq km comes to about Rs.15000 (data and processing cost).
3. Work can be carried out in shorter period in the lab.
4. Supported by GPS is more accurate and precise
5. Geomorphic approach is very important to identify the potential archaeological sites for further exploration.
6. Satellite images are the ideal aids for geomorphic analysis.
7. Digital image processing and enhancement help identifying subtle anomalous features of archaeological interest.
8. GIS helps in Data Integration.
9. Geologists and archaeologists should work hand to hand for archaeological exploration.
10. RS and GIS techniques are also used to monitor and manage the heritage sites, such as the forts, where large scale human interventions are taking place, e.g. Golconda and Warangal forts in Andhra Pradesh.
11. These technologies are used to get a picture of historic and pre-historic remains occurring below the ground surface before an excavation begins.
12. Apart from RS & GIS, near surface sensing refers to a suite of geophysical sensing techniques, including ground penetrating Radar, electrical resistivity, proton magnetometry, fluxgate and cesium gradiometry and other methods.

- 7. MESSAGE

Archaeologists in India must begin to adapt both RS and GIS technologies to the investigation of individual archaeological sites, and it is here that both show great promises for the future, because RS images have an inherent property of showing perspective view in multispectral environment with high spatial resolution.

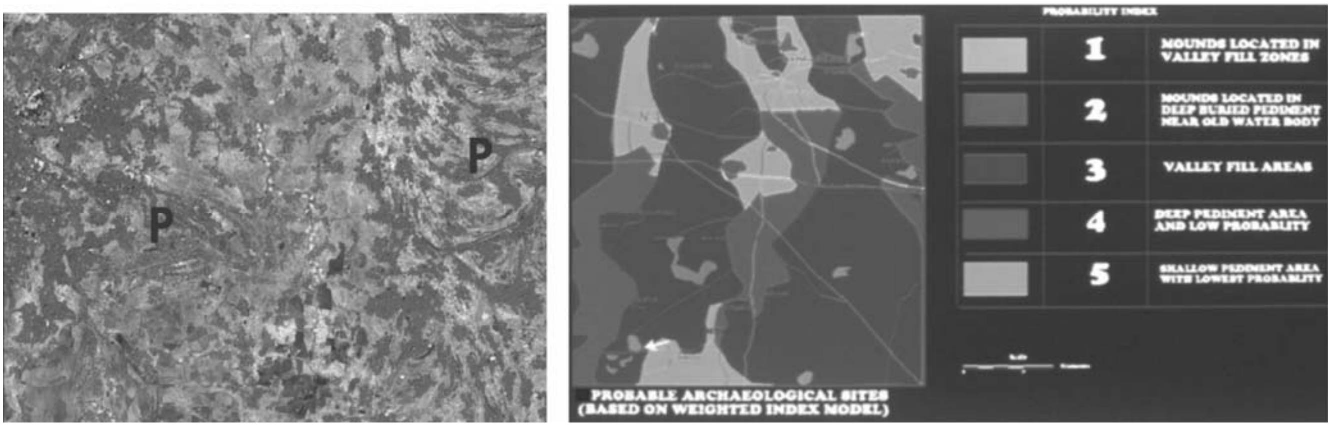
• 8. REFERENCE

Bhattacharya, Asis. 2007. Remote Sensing for Archaeology. Proc Vol on seminar ‘Remote Sensing Archaeology’, Kolkata

Sabins Jr, Floyd F. 1978. *Remote Sensing Principles and Interpretation*. Freeman and Co

• 9. ACKNOWLEDGEMENT

I thank Dr. K Vinod Kumar of NRSA, India who worked with me in this project.


P
P
PROBABILITY INDEX
1
MOUNDS LOCATED IN VALLEY FILL ZONES
2
MOUNDS LOCATED IN DEEP BURIED PEDIMENT NEAR OLD WATER BODY
3
VALLEY FILL AREAS
4
DEEP PEDIMENT AREA AND LOW PROBABILITY
5
SHALLOW PEDIMENT AREA WITH LOWEST PROBABILITY
PROBABLE ARCHAEOLOGICAL SITES (BASED ON WEIGHTED INDEX MODEL)

Figures 1-2. (1, left) Palaeochannel (P) in South 24 Parganas of West Bengai, India are the good archaeological sites. (2, right) Kondapur, Andhra Pradesh, India.

Practical use of multispectral satellite images in general Norwegian Cultural Heritage Management and focused Viking Age research. Experiences from South-Western Norway.

O.Grøn[1], F.A.Stylegar[2], S.Palmér[3], S.Aase[4]. P.Orlando[5], K.Esbensen[6], S. Kucheryavski[7]

1 Langlands Museum, Rudkøbing, 5900, Denmark, olegron_LMR@yahoo.dk

2 Vest Agder Fylkeskommune, Tordenskjoldsgate 65, 4614 Kristiansand, Norway, fransarne.stylegar@vaf.no

3 Langelands Museum, Rudkøbing, 5900 Denmark, susannapalmer@gmail.com

4 Bifrost & Draupne as, Haraldsgata 110, Postboks 420, 5501 Haugesund, Norway, sigurd@tryggebarnehager.no

5 University of Palermo, Dipartimento di Rappresentazione, Via delle Scienze (Parco d'Orleans), 90128 Palermo, Italy, pietroorlando@dirap.unipa.it

6 Aalborg University, ACABS Research Group (Applied Chemometrics, Analytical Chemistry, Sampling). Niels Bohrsvej 8, 6700 Esbjerg, Denmark, kes@aaue.dk

7 Aalborg University, ACABS Research Group (Applied Chemometrics, Analytical Chemistry, Sampling). Niels Bohrsvej 8, 6700 Esbjerg, Denmark, svk@aaue.dk

Keywords: Remote Sensing, Archaeology, Norway, Cultural Heritage

ABSTRACT

The use of high-resolution multispectral satellite images has through 2007 been applied to practical Cultural Heritage management as well as a focussed Viking Age research project in 5 study areas in South-Western Norway with 1386 registered archaeological sites. The project has so far revealed an additional 1509 anomalies interpreted as the chemical signatures of archaeological mounds, houses, roads, inhumation graves, cooking pits etc. A beginning ground-verification carried out by the county-based Cultural Heritage management system and the project itself indicates a high fraction of hits in this population of anomalies. The presentation will discuss possible methodological improvements.

1 INTRODUCTION

This paper connects two related themes: the development of multi- and hyperspectral, hence forth referred to as 'spectral' archaeological survey methodology as well as its practical application to the management of cultural heritage from the Viking Age and the younger Iron Age. Spectral recordings appear, according to our present experience, to facilitate a non-destructive and cost effective way of locating cultural heritage.

From an archaeological point of view more efficient methods for mapping and monitoring of cultural heritage is needed. Traditional field survey unaccompanied with other methods only reveals a fraction of sites that must be taken into consideration in modern cultural heritage management. The spectral survey techniques seem to facilitate an approach where qualified prognosis about the location of archaeological sites can be incorporated into the planning phase of larger projects, thus minimising the conflict between construction and cultural heritage interests and increasing time efficiency and reducing costs involved in cultural heritage management (Grøn *et al.*, 2004b; 2005).

The SW Norwegian satellite project commenced in the beginning of 2007 and is a collaboration between Vest Agder County, Norway, Trygge Barnhager as, Norway, Langelands Museum, Denmark, University of Palermo, Italy, and Ålborg University, Denmark. The project operates in 5 study areas in SW Norway in Vest Agder and Rogaland counties, in a number of the areas with a close collaboration with the local cultural heritage authorities, in order for the remote sensing data to be directly applied to cultural heritage management strategies and verified through targeted archaeological land survey. Additionally geo-chemical verification is to be carried out in 2008. The 1386 of registered archaeological sites in the study areas have through the project period been increased with an additional 1509 possible sites. In the following set of examples different aspects of our work will be presented.

2 METHODOLOGY

Spectral survey techniques are not only of importance for archaeological cultural heritage management. It also strengthens archaeological research potential, providing information about the old road systems that connected settlements and cemeteries thus facilitating a better understanding of the relation between the archaeological and historical sites in the landscape.

Parallel with the experimental use of spectral survey techniques based on visual inspection, experiments with different types of semi-automatised pattern recognition have been carried out. Algorithm-based approaches seem unable to provide a reliable distinction between non-archaeological anomalies and archaeological sites apart from those that are highly visible due to the strong and uniform spatial configurations such as mounds surrounded by circular ditches (Grøn *et al*:, 2005). Significantly better results have been obtained in preliminary experiments with multivariate techniques. However it will take years before such a methodology can be applied to practical cultural management, because of the problems with geological background noise as well as other factors. It is obvious that the application of a fully automatised pattern recognition not involving a trained observer for quality control will not become a reality in the currently visual future.

3 EXAMPLES

3.1 Iron Age cooking pits

In 2007 large clusters of geometrically irregular dark patches measuring 1-3 meters interpreted as cooking pits where observed within 4 of the 5 study areas. In Norway such cooking pits normally date to the Iron Age. The same year one of the newly observed clusters in Spangereid caused the archaeological authorities to demand a trial excavation due to the planned expansion of a plant nursery. Approximately thirty cooking pits where uncovered from the trenches. One was C14 dated to 1590 +/-50 BP (Beta-241096).

The identification and subsequent verification of the cooking pits in Spangereid has demonstrated that not only large archaeological features can be identified but also small scale archaeological features can readily be distinguished through visual inspection. Furthermore it has also proved the value of utilising satellite images as an integrated element in cultural heritage management.

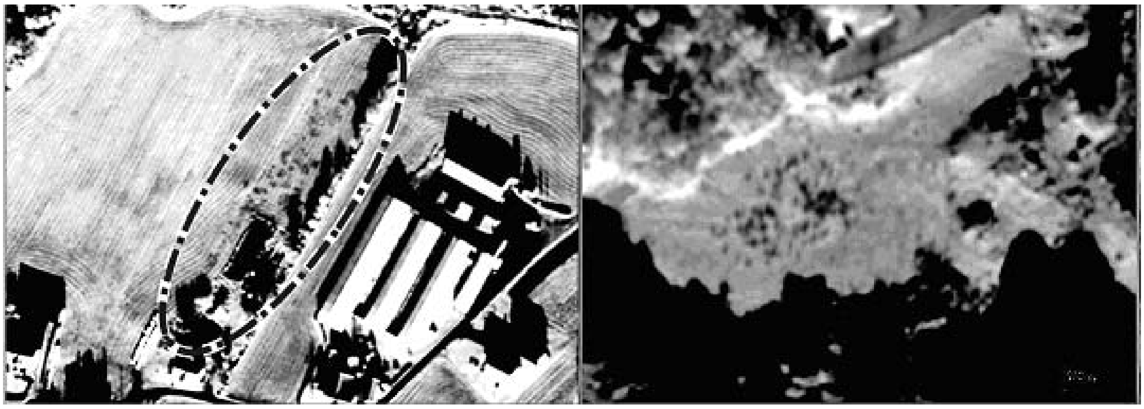


Figure 1 Left QuickBird panchromatic satellite image of cooking pits from Mitdbø, Spangereid. Right QuickBird panchromatic satellite image of possible cooking pits Eide, Karmøy. (QuickBird-copyright: Digital Globe):

3.2 The Huseby Chapel

The Norwegian cultural heritage database contains numerous 'lost' historical cultural heritage sites with their approximate positions as they are given in historical sources. One case is the royal chapel in Huseby. The chapel is one of fourteen stone built royal chapels constructed in Norway during the Medieval Period. One of the papal letters from 1308 refers to the chapel as 'Ecclesia Sancti Laurentis de Lista,' (Stylegar, 1992) the foundations still being visible in the 19th century, (fig. 2 – sketch)

The use of the QuickBird satellite imagery made it possible to pinpoint the chapel's exact location as a feature that did not fit into the pattern of old field boundaries. An anomaly measuring approximately 7 * 14 meters was observed in the panchromatic satellite image with a possible cupola measuring 5 meters in width and 3 meters in depth. Sounding with a probe proved subsequently that the observed feature conjoined with a stone foundation.

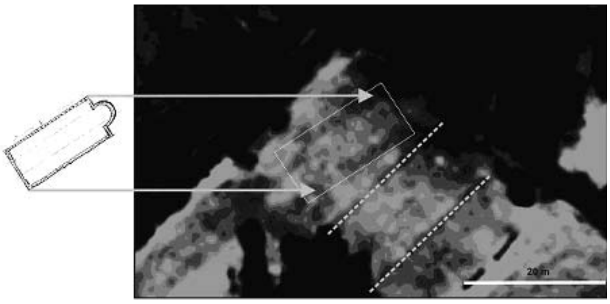


Figure 2 Right - QuickBird panchromatic satellite image of royal chapel in Huseby, Lista. Left sketch of the foundations from 1920s when they were dug free. Afterwards the information about the position was lost. Broken lines represent old field boundaries (QuickBird-copyright: Digital Globe).

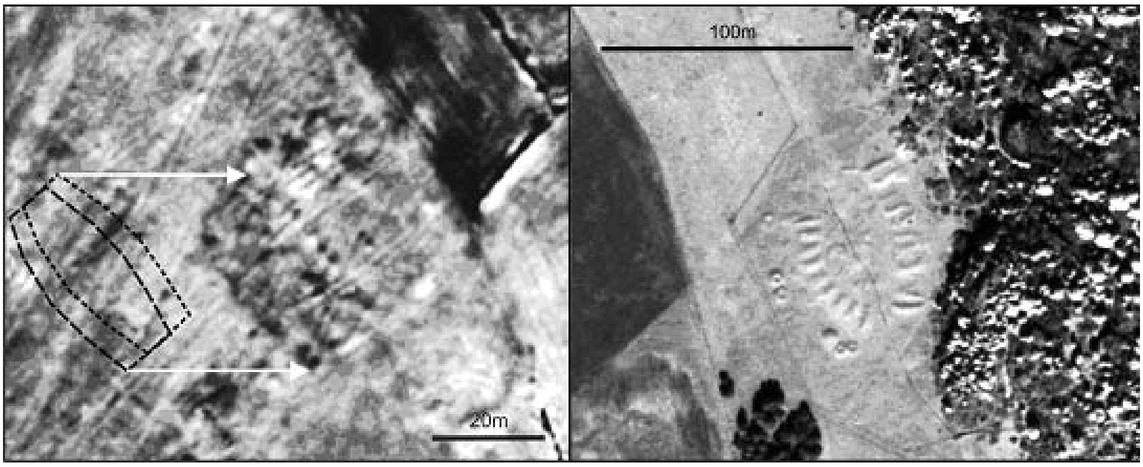


Figure 3 Left - Feature at Engeløy interpreted as a Viking Age nobility house with bending sides. Right - Feature interpreted as a military camp through excavation which is located 620 m NE of the nobility house. The raised peat walls are visible (QuickBird-copyright: Digital Globe).

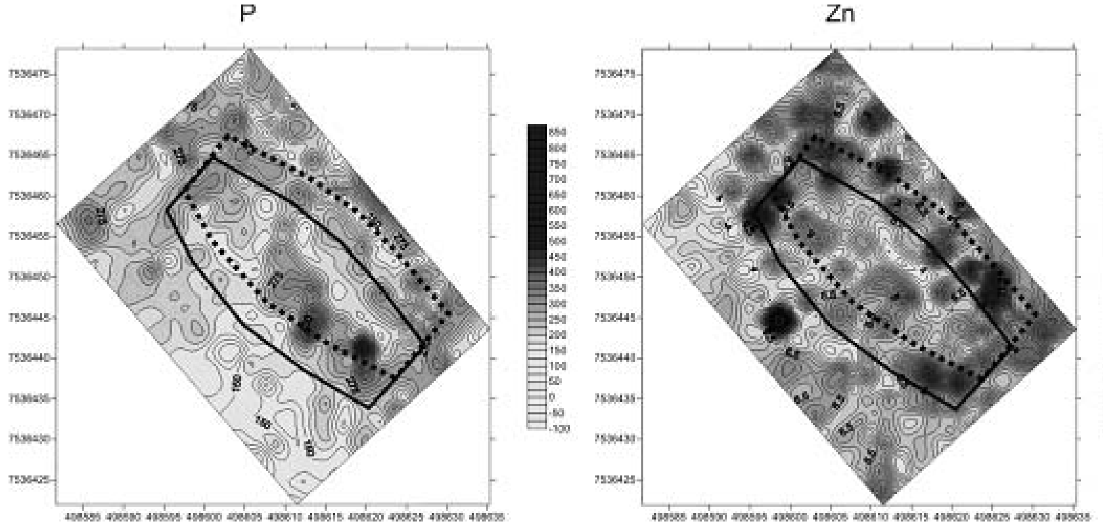


Figure 4 The feature interpreted as a Viking Age nobility house in relation to the concentration in the plough soil of – Left – phosphates (P) and – Right – zinc (Zn).

3.3 The Engeløy house

Engeløy near Lofoten a feature interpreted as a Viking Age nobility house was observed 620 m SW of a so-called 'courtyard site' construed as a military camp and dated to the Viking Age (Grøn *et al.*, 2004a; Storli, 2001). Information from the present owner has established that earlier the site was covered by peat which was removed manually earlier this century. Relatively late formation of peat covering Viking Age features is not unusual in Norway. A geo-chemical analysis of the house with samples taken in a 2 m grid for phosphates (P), zinc (Zn), iron (Fe), copper (Cu) and manganese (Mn) displayed in the plough soil features with some correspondence with the observed anomaly interpreted as two overlapping nobility houses (fig. 4). The other samples taken from the plough soil and from the sub layer display straight, linear features parallel to the house, which may reflect the distribution of the metals in the shallow sand/gravel ridge the house was located on which appears to belong to an old beach system. Alternatively is can reflect mechanical agricultural dispersal of these metals to the poor soil. Analyses of backup samples indicate that the values measured are genuine. Permission for a test excavation on the site has been applied for to the local cultural heritage authorities.

4 FROM MULTISPECTRAL TO HYPERSPECTRAL-DISCUSSION AND CONCLUSION

Mounds due to their high visibility in the landscape are the predominant type of sites registered within the Norwegian national database of cultural heritage sites *'Askeladden'*. This dominance, however, is not representative for the total population of archaeological sites that exist in the landscape. The project has in the five study areas identified hundreds of hitherto un-registered ‘invisible’ mounds (figure 5).

In addition, however, it has revealed large numbers of houses, roads and small scale features such as post holes, cooking pits and small oblong features interpreted as inhumation graves. Sites have also been located due to approximate locations given in historical sources. Many of these ‘lost’ historical sites are registered within the Norwegian cultural heritage database with imprecise locations covering several fields. With the spectral survey techniques such sites can be situated quicker and more cost effectively than by traditional field survey techniques.

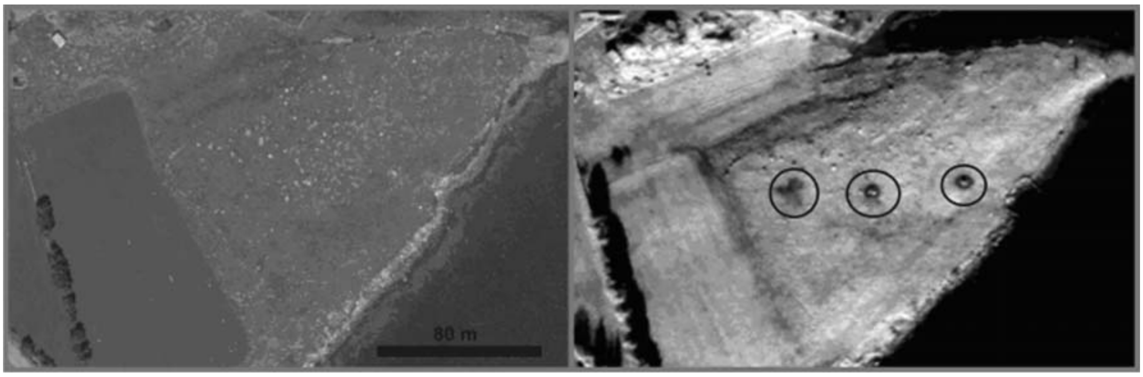


Figure 5 Left aerial photograph from Karmøy depicting same area as possible mounds seen in QuickBird image right. (www.fonnnakart.no: 1/6/08 & QuickBird-copyright: Digital Globe).

The development of recording techniques with better spectral resolution (hundreds of bands instead of the four bands available in today’s high-resolution multispectral recordings) in addition to better spatial resolution appears to facilitate a promising technological platform for the development of better cultural heritage monitoring and management systems as well as archaeological research. The increasing commercial demand for smoother geo-correction methods and improved ways of handling the enormous amounts of data collected supports such a development. The first experiences with hyperspectral images recorded with an airborne HySpex scanner support such an optimism (Grøn *et al*., 2006).

REFERENCE

Grøn, O., Aurdal, L., Christensen, F., Loska, A. 2004a. Mapping and verifying invisible archaeological sites in agricultural fields by means of multi-spectral satellite images and soil chemistry. *Proc.of Intern. Conference on Remote Sensing Archaeology* Oct. 18-21, 2004, Beijing, China, 83-90.

Grøn, O., Aurdal, L., Christensen, F., Tømmervik, H., Loska, A. 2004b. *Locating invisible cultural heritage sites in agricultural fields. Evaluation of methods for satellite monitoring of cultural heritage sites – results 2003*. The Norwegian Directorate for Cultural Heritage. Oslo.

Grøn, O., Aurdal, L., Christensen, F., Solberg, R., MacPhail, R., Lous, J., Loska, A., 2005. *Locating invisible cultural heritage sites in agricultural fields. Development of methods for satellite monitoring of cultural heritage sites - report 2004*. Research report from the Norwegian Directorate for Cultural Heritage. Oslo.

Grøn, O., Christensen, F., Orlando, P., Baarstad, I., MacPhail, R. 2006. Hyperspectral and multispectral perspectives on the prehistoric cultural landscape; the ground-truthed chemical character of prehistoric settlement and infrastructure as identified from space. *From Space to Place: 2nd International Conference on Remote Sensing in Archaeology*. (eds.) S. Campana and M. Forte. Proceedings of the 2nd International Workshop, Rome, Italy, December 4-7, 2006, 143-147

Storli, I. 2001. *Tunanleggenes rolle i nordnorsk jernalder*. VIKING 2001. 87-111

Stylegar, F.-A. 1996: Sancti Laurentis de Lista – et kongelig kapell på Huseby. Årsskrift Agder historielag nr. 72, 1996, pp. 30-36.

Comparative cluster analysis to localize emergencies in archaeology

E. S. Malinverni, G. Fangi
DARDUS, Engineering Faculty, Università Politecnica delle Marche, Ancona, 60131, Italy,
e.s.malinverni/g.fangi@univpm.it

Keywords: Remote Sensing, Quickbird, K-means, Fuzzy classification, Open source, Archaeology

ABSTRACT: In the Northwestern Peru, near the city of Trujillo, an Italian Archaeological Mission (MIPE), in tight collaboration with the INC, National Institute of Culture of Peru, works on the site of Chan-Chan, the widest archaeological complex of the world for the constructions in raw earth. The mission carried out a multidisciplinary survey with the intentions to study a methodology for the site maintenance and the creation of a local center of documentation. Inside this project we want to illustrate a step of the research based on the analysis of a QUICKBIRD high resolution image. By means of some image classification techniques it has been possible to investigate the whole archaeological site, with the aim of a better definition of its general features and of a contribution to the exploitation of the surroundings.

This analysis was carried out in open source environment performing two different algorithms and comparing the results. Not having an available set of reliable ground truth of the study area it has been inevitable to follow an unsupervised approach. The off-line clustering techniques applied have been: K-means clustering and Fuzzy K-means clustering. Both techniques rely on minimizing a cost function of dissimilarity (distance) measure, but in the fuzzy approach each data points belongs to a cluster with a fuzzy membership degree, overcoming the problem of data group overlapping. The resulted classification clearly separates the central archaeological site from the areas intensively cultivated and besides puts in evidence the coastal band, characterized by a reduced parceling and by the presence of damp zones. Another purpose of the present research has been also to individualize the principal components of the particular territorial system of Chan Chan and, possibly, to put in evidence some archaeological emergencies discovering new marks, signs. We performed every phase by the software ILWIS 3.4 (Integrated Land and Water Information System) developed by the ITC of Enschede and Open Source from July 2007.

1 INTRODUCTION

In the Northwestern Peru, near the city of Trujillo the archaeological complex of the city of Chan Chan, capital of the Kingdom Chimù, covers an area of about 14 km^2. This site, of exceptional historical-cultural value, because it is the widest archaeological complex of the world for the constructions in raw earth, is in the list of the monuments at risk of the UNESCO World Heritage. In fact it is in continuous deterioration, due to the atmospheric agents, to the uncontrolled agricultural activities, to the expansion of the area of Truijllo city and finally to the disfigurements of the so-called "tomberos". Since 2000 an Italian Archaeological Mission (MIPE), in tight collaboration with Italian CNR, Università Politecnica delle Marche (DARDUS) and the Institute National de Culture Peruvian (Inc), has carried out a multidisciplinary survey with the intentions to study a methodology for the maintenance of the site and the creation of a local center of documentation that can autonomously continue the activities of research and the formation of local technicians (Fangi et al., 2005).

In the past we pointed out a step of research based on the remote sensing high resolution image classification performed by Envi software (Galli *et al.*, 2005). Now in this occasion we present different unsupervised classification techniques implemented in an Open Source environment (ILWIS 3.4) underlying the potentiality of these solutions. We worked on a subset of the original QuickBird multi-resolution image acquired on 10-05-2003 as Standard level with a ground resolution of 2,51 m and furnished by Eurimage^{TM} (corrections of the system, radiometric corrections, geometric corrections, organization in a specific cartographic system of reference: Datum WGS84, UTM projection, 17 Fuse, South Hemisphere are given) (figure 1).

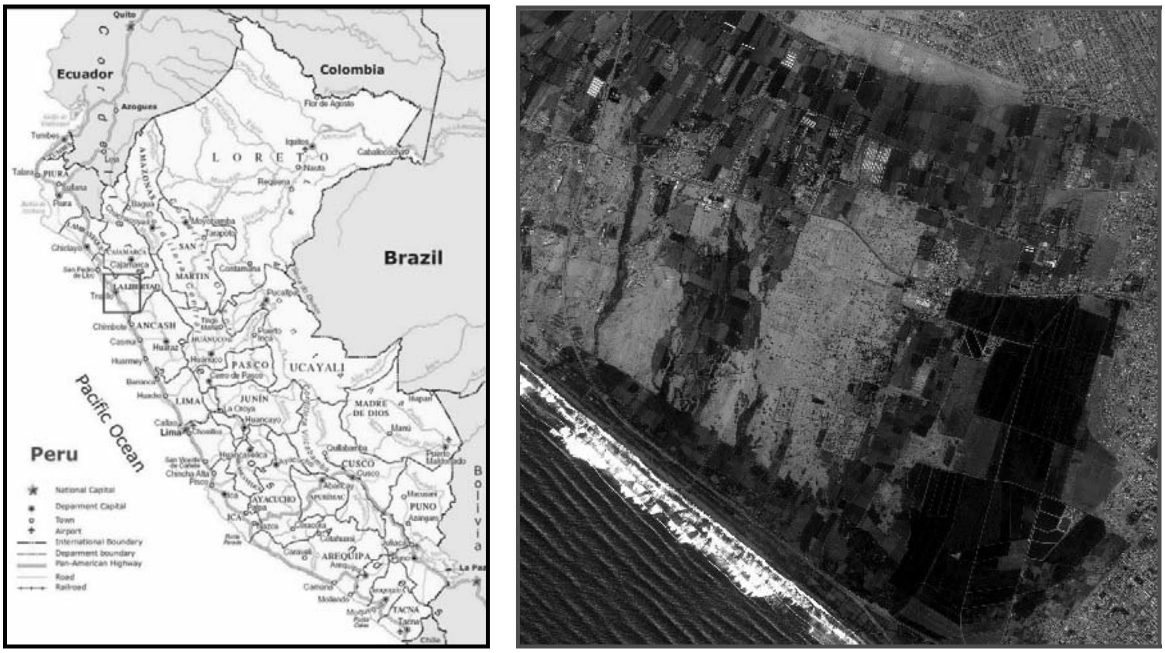


Figure 1 The Quickbid image and the localization of the area of survey

2 K-MEANS AND FUZZY K-MEANS TO COMPARE DIFFERENT UNSUPERVISED APPROACHES

The multi-resolution band combination to investigate in ILWIS was carried out making use of the correlation matrix. The Optimum Index Factor (OIF) gives the best grouping based on the minimum correlation and higher standard deviation, that indicates a good separability between the channels and which of them give much more information. In this case the near infrared band (band 4) brings many information respect to the other channels of the visible (Blu= band 1, Green= band 2, Red=band 3) putting in evidence the importance of its use (Boehler *et al.*, 2004). We chose the 2-3-4 band combination with the highest OIF.

We decided to perform an unsupervised classification not being available a set of ground truth. Starting from a conventional K-means algorithm, suitable for an "hard classification", we upgraded the methodology developing an applying the logic theory (fuzzy) to improve the knowledge of land cover assessment. For this purpose the ILWIS software allows to use some internal functions and mathematical calculations in a sequence of instructions organized in script format. This is a very simple way to elaborate the data combining procedures already inside the software with other realized ex-novo according to the spirit of the free open source environment. The ILWIS script consists of set of commands that can be used with input parameters (the variables) which make the procedure more than customizable (Malinverni, 2008).

In this section we used the results of both classifications, K-means and Fuzzy K-means, to put in evidence the principal characteristics of the land grouped in the clusters. Both techniques rely on minimizing a cost function of dissimilarity (distance) measure, but in the fuzzy approach each data points belongs to a cluster by a fuzzy membership degree defining better the grouping of data. The resulted classification clearly separates the central archaeological site from the areas intensively cultivated and besides it puts in evidence the coastal band characterized from the small zones of water, moreover, the classification highlighted several particular emergencies. The difficulty has been the assignment of classes because many pixels contained mixed spectral characteristics reflecting in this way a mixture of surface-cover classes. In this case the "soft classification" (fuzzy) can help the evaluation of the partitions of thematic classes in a single pixel assigning a membership degree into a class (Burrough, 1989). According to these considerations it is possible to note that the efficiency of the clustering methods have a proportional reduction in relation to the amount of overlapping between the classes.

In both classified images there are in evidence some characteristics zones with diversified features: the principal archaeological site of Chan Chan (the center); a region of intensive cultivations (South - East); a region of mixed cultivations (North); some parcels without vegetation and modified by anthropic phenomena (West and North) and finally some areas fully urbanized (West and Northwest) (Figure 3, left). The central zone of the image is characterized by open grounds (yellow and cyan) that have been classified by the algorithm unsupervised as structures of the archeological site and they are well separable by the cultivated area (Figure 3, right).

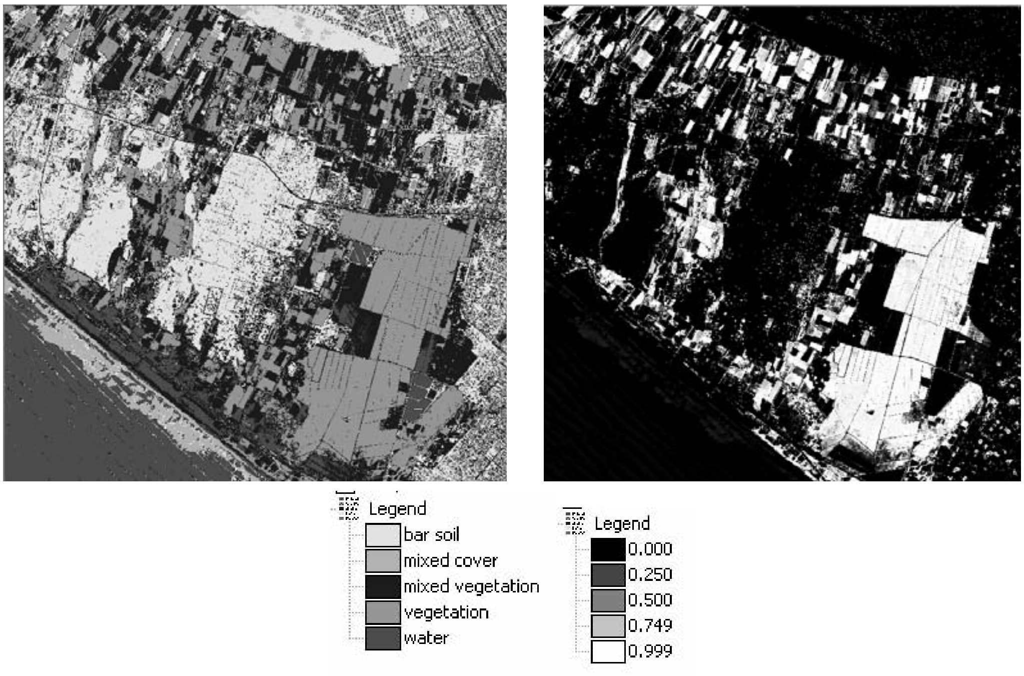


Figure 3 The unsupervised K-means classification (3 runs, 5 classes)(left) and the Fuzzy K-means membership degree for the vegetation class (right)

Moreover, the classification highlighted the perimeter of the buildings with a presence of the vegetation more or less developed that colonized the archaeological area. The spreading expansion of the agriculture, destructives for the archaeological features, is remarked in the Southeast cultivated fields, where the probable rests of one of the typical terraces pyramids are localized (figure 4).

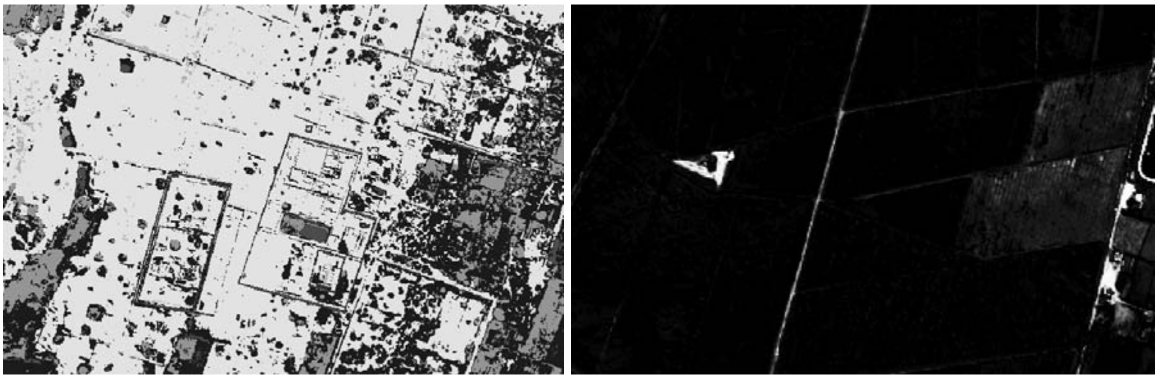


Figure 4 Some other archeological structures in evidence both in hard and soft classification

3 THE USE OF THE FUZZY CLASSIFICATION TO POINT OUT THE ARCHEOLOGICAL EMERGENCIES

In this section we used the different performances of the Fuzzy K-means algorithm to improve the knowledge of the territory and in particular to point out the archeological emergencies. This is possible by taking into account the overlapping class into the pixels with mixed spectral values assigning a membership probability value to each cluster. The membership value is in a range between 0 (not a class member) and 1 (wholly and only in a class) but it can be expressed on an intermediate scale. The maximum degree of fuzziness identifies the highest membership value to a class. The continuous sequence of gray values represents the membership degrees for each cluster: the dark gray signifies no membership and white represents 90-

100% of membership. The fuzzy classification output displays in raster map the maximum probability for each pixel to belong to a class (figure 5). Furthermore it provides information regarding the overall spectral separation among the various classes. Once the membership values have been calculated, an observation can be assigned to a “hard class” formed by all the observations that have their highest membership on the same class generating a thematic map representation (defuzzification) (figure 5).

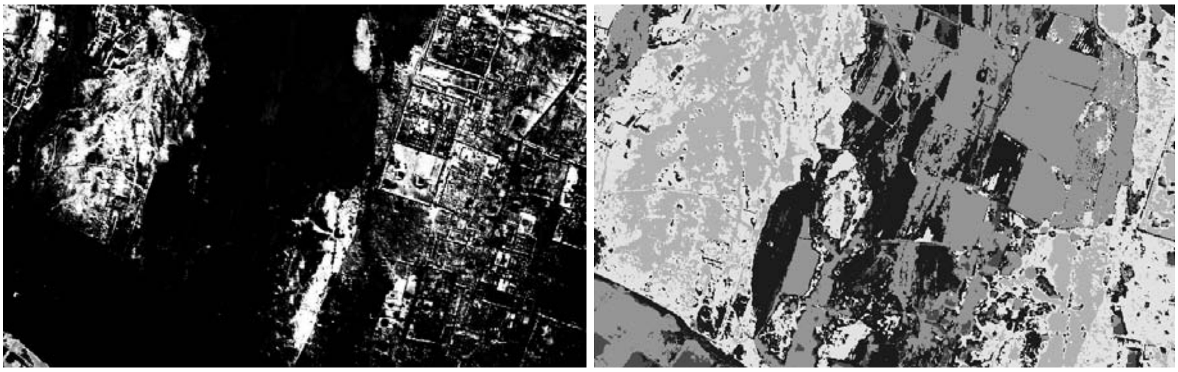


Figure 5 The max membership degree map of the mixed cover class puts in evidence the archeological structures better than the thematic map (defuzzified)

4 CONCLUSION

The motivation for this choice has been manifold: very encouraging results have been obtained as a better identification of the archeological structures into the cover mixed class. In fact observing the thematic map there are not well defined elements in the archeological zones and too much mixed covers in the surroundings. On the contrary analyzing the single fuzzy membership maps there is the possibility to separate the information suggesting the identification of new emergencies too.

5 REFERENCES

Boehler, W., Heinz G., Qiming G., Shenping Y. 2004. The progress in satellite imaging and its application to archaeological documentation during the last decade, *Proceeding of the International Conference on Remote Sensing Archaeology*, Beijing, China.

Burrough, P.A., 1989. Fuzzy mathematical methods for soil survey and land evaluation. Journal of Soil Science, 40, 477-492.

Fangi, G., Malinverni, E.S., Schiavoni, A. 2005. Integrated Surveying Techniques For The Archaeological Park Of Chan-Chan In Peru, *XX Symposium of CIPA, the ICOMOS & ISPRS Committee “International cooperation to save the world's cultural heritage”*, Turin, Italy, 259-264.

Galli, A., Fangi, G., Malinverni, E. S. 2005. Analisi e valorizzazione del sito archeologico di Chan-Chan mediante immagini Quickbird, *AIIA2005 “L’ingegneria agraria per lo sviluppo sostenibile dell’area mediterranea”*, 27-30 June 2005, Catania, Italy.

Malinverni, E.S. 2008. Free Open Source ILWIS 3.4 for efficient thematic studies in Alpine areas, *XXI Congress of ISPRS “Silk Road for Information from Imagery”*, 3-11 July 2008, Beijing, China.

Usability of IKONOS images as a basis of data capture for the NascaGIS

C. Richter, B.Teichert
University of Applied Sciences Dresden (HTW), Faculty of Geodesy and Cartography, Friedrich-List-Platz 1
01069 Dresden, Germany. E-Mail: [crichter, teichert]@htw-dresden.de

Keywords: NascaGIS, Data Capture, DTM, SRTM, IKONOS

ABSTRACT.
The primary requirements of any GIS application are the data, which can be obtained e.g. by field measurements, photogrammetric techniques or very high resolution (VHR) satellite images. The potential of the VHR satellite images allows the extraction of accurate spatial information for a multiplicity of GIS applications. In general, VHR images can be used for data capture; it only depends on the accuracy to be achieved. Because of the special astronomical investigations in the Nasca Project Dresden, sub-meter accuracy is needed.

The two major questions to be answered are the influence of the DTM (Digital Terrain Model) accuracy on the orthorectification of the satellite data and the accuracy of the data capture itself. Besides of the existing DTM's, worked out by digitizing contour lines, especially the SRTM data were analyzed regarding to their usability for the orthorectification of the IKONOS data.

The orthorectification with SRTM-1 (X-Band) as well as with SRTM-3 (C-Band) has brought very good results in the plain of the Pampa of Nasca, where sub-pixel accuracy was achieved for the vector data capture. More problematic are the mountainous areas, because the partially large height discrepancies affect significantly the orthorectification especially of the off-nadir satellite images, which result in less accuracy of the vector data. Nevertheless, because most of the lines and figures at the Pampa of Nasca are situated in the flat area, the orthorectified satellite images can be used for the GIS data capture in an adequate accuracy.

1 INTRODUCTION

One of the most fascinating mysteries of the world are the famous Lines and Figures at the Pampa of Nasca and Palpa in the south of Peru, which have their seeds in the pre- Columbian Nasca culture (approx. 200 BC – 650 AC). Several hundred square kilometers of rock strewn desert are covered with thousands of lines, large biomorph figures and various geometric shapes. Because of the dry and stable climate, the light-colored traces have remained nearly unchanged during the last 2000 years. But today this world cultural heritage is threatened with destructions.

The Dresden born researcher Dr. Maria Reiche was the first one who fought against the destruction of the Nasca Lines. It's not possible to enumerate all her efforts and activities. Not least because of her engagement the lines where added to the UNESCO World Heritage List in February 1995. In memoriam of Maria Reiche and in order to help to protect and preserve the cultural heritage of Nasca and Palpa a scientific project was originated by members of the association "Dr. Maria Reiche" e.V. in Dresden, Germany. One of the main objectives of the Nasca Project Dresden is the digital conservation of the lines and figures of Nasca and Palpa. The basis of this Nasca project is a Geographical Information System (NascaGIS), which shall preserve this cultural heritage at least in digital form and provide an easy digital access to the public at large. (Richter, 2007a)

The primary requirements of any GIS application are the data, which can be obtained e.g. by field measurements or photogrammetric techniques. The most practical solution to capture the geometrical information of this huge area to an adequate accuracy is the photogrammetric approach. Unfortunately the available aerial photos cover only the main area of the Pampa of Nasca (figure 1). For this reason the usability of very high resolution satellite images as a basis for the data capture in the remaining region had to be investigated.

2 AVAILABLE DATA IN THE INVESTIGATION AREA

The study area (approximately 580 sq km) is located in the South of Peru between the Pacific Ocean and the foothills of the Andes North of the little town Nasca (see figure 1). It includes the whole Pampa of Nasca, a nearly flat terrain with bare ground, delimited by the mountains in the west and the Ingenio valley in the North.

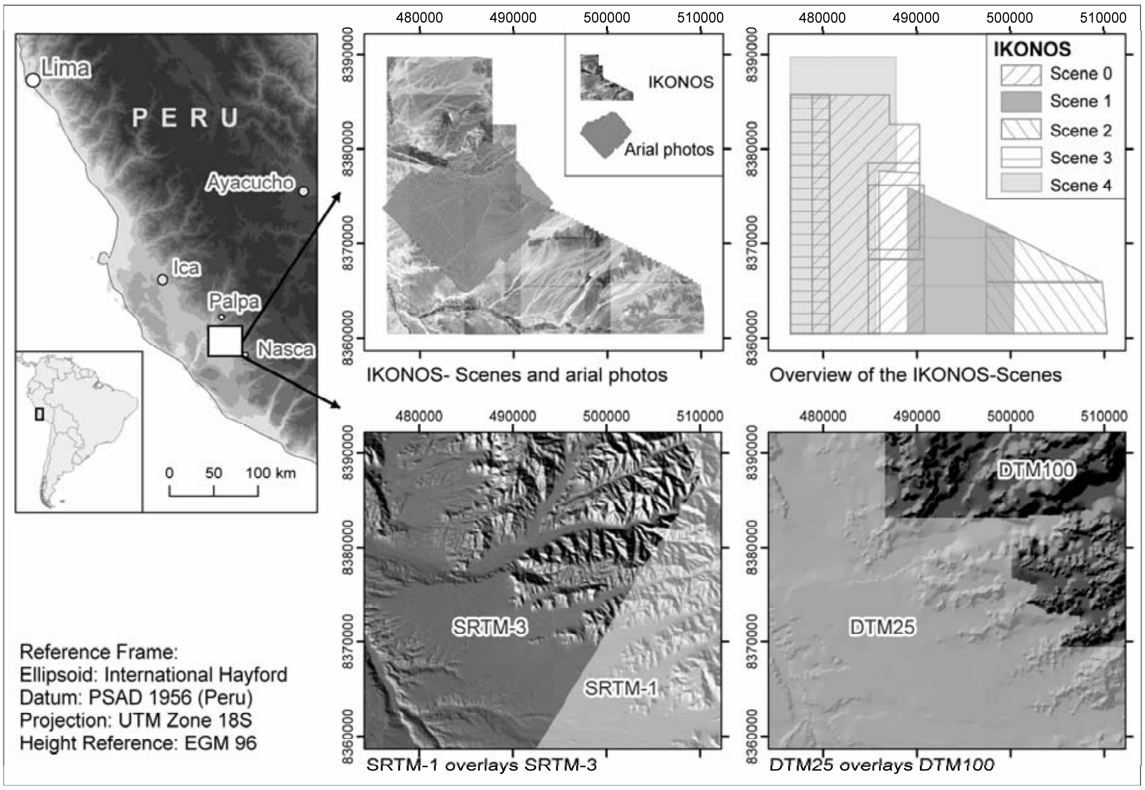


Figure 1. Overview of the study area and the available data

To cover the whole investigation area five IKONOS scenes in eleven tiles from 2000 and 2001 were used. The IKONOS sensor generates approx. 1 m panchromatic and 4 m multispectral images depending on the viewing angle. The scenes 0, 1 and 2 were provided as pansharpened data with 1 m resolution and scenes 3 and 4 as panchromatic plus multispectral data. All the scenes were available as Carterra Geo Ortho Kit Product consisting of the high-resolution Geo images and auxiliary Rational Polynomial Coefficient (RPC) files, which provide the sensor geometry. The acquisition parameters are summarized in Table 1.

Parameter	Scene 0	Scene 1	Scene 2	Scene 3	Scene 4
nominal collection azimuth	19.8731°	46.4443°	264.0727°	295.8129°	170.4125°
nominal collection elevation	72.04422°	87.24905°	56.06464°	58.20786°	72.89145°
sun angle azimuth	34.7991°	34.6010°	40.0705°	40.4531°	106.9303°
sun angle elevation	43.91391°	44.02104°	48.11153°	47.88911°	60.83793°
nadir angle	17.95578°	2.75095°	33.93536°	31.79214°	17.10855°

Table 1. Acquisition Parameters of the IKONOS scenes

Since the RPC-file expresses the complete and accurate sensor geometry, the accuracy of the orthorectification of the IKONOS data is defined by the accuracy of the Ground Control Points (GCP) and the Digital Terrain Model (DTM).

During our GPS campaign in 2004 more than 2000 contour points where measured in the Pampa of Nasca, whereas approx. 80 points are appropriate as GCP's for the orthorectification of the IKONOS data. The measuring accuracy of these GCP's is better than 5 cm, while the identifiability inside the Pampa is about 10 - 30 cm.

The other important data for the orthorectification is the DTM. During the last years different DTM's were developed within the Nasca Project Dresden. A high-precision DTM was generated from the photogrammetric aerial photos by using the software LPS, but it covers only a small part of the Pampa of Nasca. Therefore years ago a regional DTM was worked out by digitizing contour lines and single points from existing topographical maps. At the end of the 90th there were only maps in the scale 1:100.000

available (DTM100). Later we've got cadastral maps of the main part of the Pampa in the scale 1:25.000 (DTM25). The DTM100 spans over the entire study area whereas the DTM25 covers only the main part of the Pampa of Nasca (see figure 1).

Today it's possible to use the results of the Shuttle Radar Topography Mission (SRTM), which obtained elevation data of the earth surface with data points spaced every 1 arc second (≈ 30 m) of latitude and longitude (SRTM-1). During the mission two antenna pairs operating in C-band and X-band were used. The C-band interferometer, with its swath width of 225 km, covers 119 million km2 of the entire landmass between 60°N and 54°S. The X-band provides only half of this area due to its swath width of 45 km. (Rabus *et al.*, 2003)

The C-band data with a spatial resolution of 3 arc seconds (SRTM-3) are available for free on the Internet (LP DAAC 2005). These C-band data covers the entire investigation area, whereas the X-band data are available only for the eastern part (see figure 1).

3 ANALYSIS OF THE DTM ACCURACY

The comparison of the different DTM's has shown considerable differences in the mountainous regions. To analyze the accuracy, 1116 common points, measured with GPS, had been used. The rough results are given in Table 2.

DGM	Minimum [m]	Maximum [m]	Mean [m]	Standard deviation [m]
SRTM-1	- 6.85	16.60	- 0.47	2.44
SRTM-3	- 10.06	32.34	0.79	2.90
DGM25	- 28.89	62.67	2.62	6.79
DGM100	- 34.52	76.14	- 6.46	14.77

Table 2. Differences between the 1116 GPS points and the DTM's

As expected the SRTM-1 data has shown the highest accuracy, but this DTM does not cover the whole investigation area. Since the comparison of the GPS points with SRTM-3 has yield also good results, this DTM is appropriate for further research. The accuracy of DTM25 and DTM100 is considerably lower and after extensive investigation rough errors were detected. Hence these DTM's are not recommendable for further use.

In addition to those results two other comparisons had been evaluated, the differences of SRTM-1 and SRTM-3 and the comparison of SRTM-3 with the photogrammetric DTM. The differences between SRTM-1 and SRTM-3 are less than 5 m in flat terrain and between ± 60 m in mountainous regions with maximum differences of ± 350 m. The comparison of SRTM-3 with the photogrammetric DTM has brought very good results with differences less than ± 3 m in the flat terrain of the Pampa of Nasca. At the edge of the Ingenio valley in the north of the Pampa the differences between the two DTM's are in the range of ± 40 m. It results from the precipitous area with slopes of 62° and the spatial resolution of the SRTM-3 data (see Fig. 2). In the nearly flat terrain of the Pampa of Nasca the SRTM-3 data is very much appropriate for the orthorectification. (Richter, 2007b)

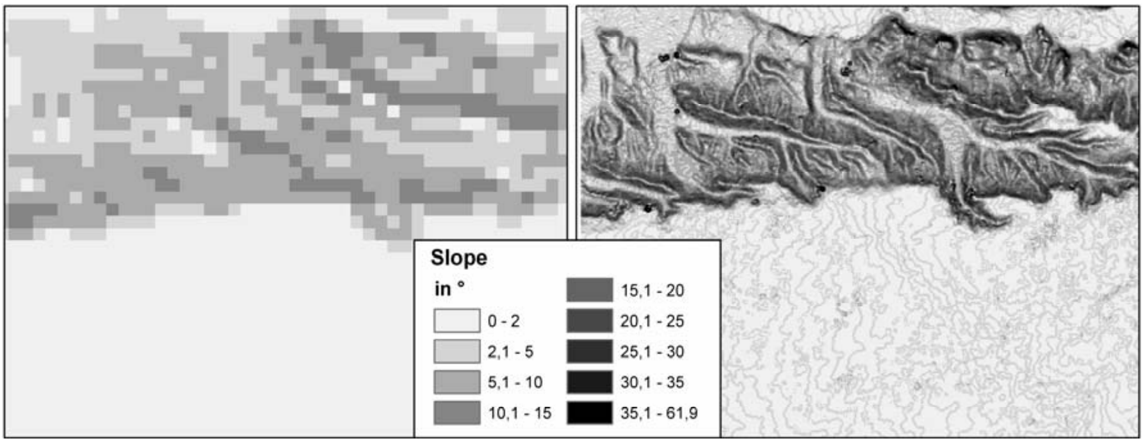


Figure 2. Comparison of the slopes between SRTM-3 (left) and photogrammetric DTM (right)

4 ORTHORECTIFICATION AND VECTOR DATA CAPTURE

The accuracy of the orthorectification of satellite images depends on the accuracy of the DTM and the GCP's. Of minor importance for the orthorectification of IKONOS images is the number of GCP's. One or two GCP's are really sufficient when RPC-data is available; more GCP's will not improve the result (Jacobsen, 2005). The DTM accuracy has much more influence on the result of the orthorectification of satellite images (see e.g. Toutin & Cheng, 2001). The accuracy of the orthorectified image becomes worse in mountainous regions, especially if the images were acquired with off-nadir viewing angles, which is quite common for IKONOS imagery. The tangent of the nadir angle determines the influence of the height difference in the DTM. That means, e.g. in scene 2 (tan 34° = 0,67) the horizontal displacement equates approx. 2/3 of the height error. Very detailed investigations confirmed this dependency (Richter 2007b). By using only GCP's in the flat area an overall RMSE less than one meter was achieved, although in scene 2 a maximum horizontal displacement in the mountainous area of approx. 40 m can be expected. For the triangulation of all IKONOS tiles 49 GCP's in the flat area, several tie points, SRTM-3 and RPC-data were used. In the mainly flat terrain of the Pampa a sub-meter accuracy within the scenes 0, 1 and 4 (nadir angle < 18°) and a maximum horizontal displacement of 3 m within the scenes 2 and 3 (nadir angel > 31°) were achieved.

Because of the special astronomical investigations in the Nasca Project Dresden, sub-meter accuracy is needed (Teichert, 2007). To achieve this high accuracy for the NascaGIS two points of interest had to be considered; on the one hand the accuracy of the orthorectification and on the other hand the accuracy of the vector data capture. Thereby the recognisability of points in the images is a crucial factor. The following results are related to points which could be very good identified. Independent and multiple measurements within the orthorectified image resulted in a relative horizontal accuracy between 10 cm and 30 cm. The comparison of these measurements with the available GPS-coordinates has shown an absolute accuracy of less than one meter for points inside the flat Pampa, where most of the lines and figures of Nasca are situated. In the scenes with a nadir-angle of about 33° a horizontal shift of 3 m could possibly occur based on the accuracy of the SRTM data. (Richter, 2007b)

5 RESULTS

The orthorectification with SRTM-1 (X-Band) as well as with SRTM-3 (C-Band) has brought very good results in the plain of the Pampa of Nasca. Sub-meter accuracy was achieved for the vector data capture. More problematic are the mountainous areas, because the partially large height discrepancies of the DTM affect significantly the orthorectification, especially the off-nadir satellite images, which result in less accuracy of the vector data. Nevertheless, since most of the lines and figures at the Pampa of Nasca are situated in the flat area, the orthorectified satellite images can be used for the GIS data capture in an adequate accuracy.

ACKNOWLEDGMENT

Thanks are going to SLSA (Swiss-Liechtenstein Foundation for Archaeological Research Abroad) and the ETH Zürich for lending some aerial photos of Nasca.

REFERENCES

Jacobsen, K. 2005. Vergleich der Orientierungsverfahren für Weltraumaufnahmen. In: E. Seyfert (Hrsg.) GEO-GOVERNMENT. Wirtschaftliche Innovation durch Geodaten, Bd. 14, S. 467-474. Rostock. ISSN: 0942-2870.

LP DAAC. 2005. USGS-FTP-Server : SRTM-3 (Version 2) Data for South America. ftp://e0srp01u.ecs.nasa.gov/srtm/version2/SRTM3/South_America/ (20.06.08).

Rabus, B., Eineder, M., Roth, A. Bamler, R. 2003.The Shuttle Radar Topography Mission (SRTM) - A New Class of Digital Elevation Models Acquired by Spaceborne Radar. In: I*SPRS Journal of Photogrammetry & Remote Sensing*, 57 : 241-262. http://elib.dlr.de/447/ (20.06.2008).

Richter, C. 2007a. NascaGIS - An Application for Cultural Heritage Conservation In: *Dresdner Kartographische Schriften: Nasca Symposium 2006*, Bd. 7, S. 115-126. ISSN: 1436-0004.

Richter, C. 2007b. *Orthorektifizierung von IKONOS- Szenen als Grundlage für die GIS- Datenerfassung im Gebiet der Pampa von Nasca/Peru.* Master Thesis am Zentrum für GeoInformatik Universität Salzburg.

Teichert, B. 2007. Astronomical investigations of the Nasca lines. In: *Dresdner Kartographische Schriften: Nasca Symposium 2006*, Bd. 7, S. 87-101: HTW Dresden. ISSN: 1436-0004.

Toutin, T., Cheng, P. 2001. Orthorectification and DEM Generation from high resolution satellite data. Paper presented at the 22nd Asian Conference on Remote Sensing, Singapore. www.crisp.nus.edu.sg/~acrs2001/pdf/070cheng.pdf (01.04.2008).

GIS-based archaeological analysis of large areas in the Peruvian Andes based on high resolution satellite imagery

M. Sauerbier[1], P. Fux[2], H. Eisenbeiss[1]

[1]Institute of Geodesy and Photogrammetry, ETH Zurich, Wolfgang-Pauli-Strasse 15, 8093 Zurich, Switzerland, E-mail: {martin.sauerbier, henri.eisenbeiss}@geod.baug.ethz.ch

[2]Dept. of Pre- and Protohistory, University of Zurich, Karl-Schmid-Strasse 4, 8006 Zurich, Switzerland, E-mail: peter.fux@access.uzh.ch

Keywords: Archaeology, Cost Surface Analysis, DTM/DSM, GIS, High Resolution Satellite Imagery

ABSTRACT: In this paper, we present a concept for a combined archaeological and spatial study on possible interregional trade route connections indicated by archaeological sites which presumably mark important waypoints on these routes. High resolution satellite imagery is proposed to be applied for DTM/DSM generation as well as for visual interpretation for site prospection due to its great potential for mapping and terrain modeling for large areas. Based on these data, cost surface analysis provides a valuable tool for the evaluation of pathways in terms of traveling time and effort. The concept is demonstrated for a subset of the area of investigation based on low resolution, but freely available, SRTM-90 data.

1 INTRODUCTION

In the Andean and circum-Andean region interactions of people between different ecological zones are a crucial cultural pattern. The exploitation of many different ecological zones, in combination with cultural interactions and material exchange, can be seen, among other reasons, as an adaptation to extreme topographic and climatic situations and a reduction of a substantial risk (e.g. Murra, 1972; Moseley, 1992, pp 25-51). Legitimately, one could even argue that the extraordinary topographic and climatologic conditions of that region once evoked – or at least allowed – the development of several pristine civilizations, such as the archaeological cultures of Chavín, Wari or Inca (see e.g. Burger, 1995).

In the area of investigation of the archaeological Nasca-Palpa Project from the German Institute of Archaeology at the southern Pacific coast of Peru, a good deal of evidences of above-discussed inter-ecozonal interactions were documented during the last eleven years of investigation.1 Obsidian artifacts, for example, found e.g. in the graveyard of Jauranga (Reindel & Isla, 2004), near Palpa (350 m a.s.l.), dated to the Paracas Period (800-200 B.C.), are evidence of interaction between people from the highlands and the coastal lowlands, since obsidian exclusively occurs in the highlands (Fux 2007, Silverman and Proulx 2002, pp 65-66). Vice versa, Paracas-style ceramic findings in the highlands are further evidence for interaction (Hohmann, 2006, p 44).

Our research project at Chichictara2, which is the largest petroglyph site in the Nasca-Palpa region, revealed the footsteps of such interactions (Fux et al. in press). Chichictara is situated 11 km to the northeast of Palpa at an altitude of around 550 meters above sea level. Approximately 150 sculptured rocks are covered with anthropomorphic, zoomorphic and geometric figures or with depictions of activities. On the basis of iconographic similarities with datable archaeological findings, most of these petroglyphs date to the Paracas Period (800-200 B.C.). At this point, our discovery of an ancient footpath connecting Chichictara with the petroglyph site Letrayoc, newly found by T. Stöllner (Ruhr-Universität Bochum, Germany), situated in the highlands at an altitude of approximately 3200 m a. s. l. is illuminative.

The distance between these two sites is within the walking distance of one day. The cost surface analysis we conducted on the basis of a DTM derived from SRTM-90 (Shuttle Radar Topography Mission) data confirms our postulation of the footpath on the mountain ridge (figures 1, 2). Thus, – by taking into account further consideration (see Fux et al. in press) – we dare to argue that the petroglyph sites Chichictara and Letrayoc once had the social function of resting places for caravans on the way between different ecological (and cultural) zones, or as their hand-over places. This hypothesis is further confirmed by the petroglyphs found at the rock shelter of Coyungo, since the estimated walking times between Letrayoc, Chichictara and

---

[1] The Nasca-Palpa Project is coordinated by Markus Reindel (German Archaeological Institute, Commission for Archaeology of Extra-European Cultures (KAAK), Bonn, Germany) and Johny Isla Cuadrado (Instituto Andino de Estudios Arqueológicos (INDEA), Lima, Peru). For further information regarding the project, see e.g. Reindel 2004.

[2] The Chichictara Project is conducted by Peter Fux (Department of Pre- and Protohistory of the Institute of History, University of Zurich), Martin Sauerbier (Institute of Geodesy and Photogrammetry, ETH Zurich), Thomas Kersten and Maren Lindstaedt (Department Geomatics, HafenCity University Hamburg).

Coyungo coincide with a one day's stage of a pedestrian (see section 3). The same applies to the distance between Coyungo and Monte Grande, an important archaeological settlement site from the Paracas period amongst others, which presumably was the regional access to the sea.

Whereas cultural interactions during the Paracas Period (800-200 B.C.) between inhabitants of the highlands and the costal lowlands are well comprehensible, both at Chichictara and at Letrayoc depictions of monkeys advert to even further interactions with people from the rainforest at the eastern slope of the Andes.

In the following we present our approach for an enhancement of the area of investigation in order to obtain new information regarding inter-ecozonal interactions during the above-mentioned archaeological period by means of spatial and archaeological data.

2 DSM GENERATION FROM HIGH RESOLUTION SATELLITE IMAGERY

Nowadays, an important development can be observed in the field of remote sensing. More and more private companies in several countries operating earth observation satellites commercially as well as national space agencies and public organizations make high resolution imagery available to the market, while the provided radiometric, geometric and spectral resolution and the area covered by a scene as well as the prices differ significantly. Modern satellite platforms usually carry linear array CCD sensors for image acquisition onboard, e.g. IKONOS, QuickBird or ALOS etc. (Jacobsen, 2003).

The high potential of accuracy provided by satellite imagery for georeferencing, point positioning, DSM generation and orthoimage generation purposes was shown during various tests performed by Kersten et al.(2000), Toutin & Cheng (2000), Baltsavias *et al.* (2001), Jacobsen & Passini (2003), Eisenbeiss *et al.* (2004), Poli *et al* (2004), Zhang & Gruen (2004), Jung *et al.* (2005), Baltsavias *et al.* (2006), Poon *et al.* (2006). Satellite imagery can serve as a worthwhile alternative to aerial images in cultural heritage applications, e.g. for prospection, DTM generation and mapping of large sites, although geometric resolution is still inferior compared to aerial images and therefore, satellite images are not suitable for every purpose.

3 GIS-BASED ANALYSIS

The so far known archaeological evidence in the wider Nasca region leads to the question if connections between sites at an interregional level existed in earlier periods. Pathway analyses therefore are a suitable tool to study possible connections in terms of effort and time needed to travel from A to B. As a basis for such investigations, DTMs and DSMs at different resolutions and accuracies can be deployed for the determination of cost surfaces (Sauerbier *et al.*, in press). Using the SRTM-90 DEM, we produced a cost surface according to Tobler's estimated hiking time function according to (Tobler, 1991):

$$W = 6 * \exp(-3.5 * abs(S + 0.05)),$$

where W is the hiking time in km/h and S is the slope formulated as dx/dh.

As a result, we can calculate approximate hiking times between locations based on given pathways or determine least cost pathways between locations. Figure 2 shows a subset of the cost surface, from which one can already recognize where traveling is more advantageous and where not. Nevertheless, the SRTM-90, due to its low resolution, is only suited to determine pathways at a level that allows to predict the choice of route made by travelers in terms of which valley was used, but not to determine where exactly a path proceeded though one can recognize that valley ground or smooth mountain ridges show higher walking speed values. For this purposes, we plan to use the higher resolution DSMs derived from high resolution satellite imagery, which might help in answering the question if travelers would have more likely preferred the valley ground or the surrounding slopes or even the mountain ridges.

4 OUTLOOK

The presented concept of a combination of archaeological data, spatial data acquisition for DTM/DSM generation and cost surface analyses, demonstrated in a preliminary study using SRTM-90 data, should be understood as a proposed workflow for a more comprehensive future study. We plan to enhance the area of investigation (figure 1) towards the Andes and further to the adjacent rainforest in the eastern lowlands. This enhancement is indicated by the iconography of the above mentioned petroglyphs at Chichictara and Letrayoc.An important prerequisite for the achievement of reliable results is the availability of DTM/DSM data of higher resolution and higher accuracy than the herein used SRTM-90 DEM. Based on such high resolution DTMs, we plan to apply the presented procedure as a support for archaeological surveys by use of predictive modeling methods in order to detect footpaths and hand-over / resting places for caravans transporting trade goods between different climatic (and cultural) zones.

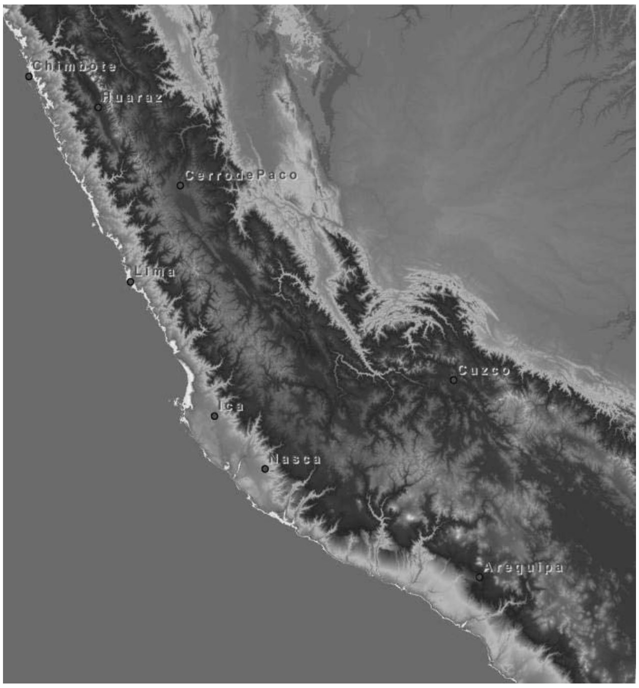


Figure 1: SRTM-90 for the area of investigation in Peru. The emosaiced tiles in UTM Zone 18 S system contain coastal, mountainous and rainforestal regions.

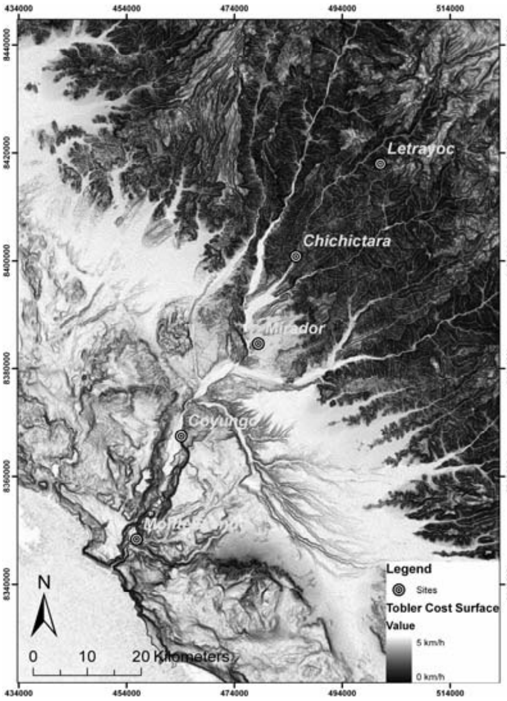


Figure 2. Cost surface according to Tobler's empirical hiking time function indicating the estimated walking speed in km/h for each cell. Note that bright areas feature high walking speed while dark areas only allow slow walking.

5 RERENCES

Baltsavias, E. P., Pateraki, M., Zhang, L. 2001. Radiometric and Geometric Evaluation of IKONOS Geo Images and Their Use for 3D Building Modeling. Joint ISPRS Workshop on "High Resolution Mapping from Space 2001", Hannover, Germany, 19-21 September (on CD-ROM).

Baltsavias, E., Zhang, L., Eisenbeiss, H. 2006. DSM Generation and Interior Orientation Determination of IKONOS Images Using a Testfield in Switzerland. *Photogrammetrie, Fernerkundung, Geoinformation*, 1 : 41-54.

Burger, R. L. 1995. *Chavín and the Origins of Andean Civilization.* Thames and Hudson, London.

Eisenbeiss, H., Baltsavias, E., Pateraki, M., Zhang, L. 2004. Potential of Ikonos and Quickbird imagery for accurate 3D point positioning, orthoimage and DSM generation. Proc. 20th ISPRS Congress, Istanbul, Turkey, 12-23 July, In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXV, Part 3 : 522-528 (and on DVD).

Fux ,P., Sauerbier, M., Kersten, T., Lindstaedt, M., Eisenbeiss, H., in Press. Perspectives and Contrasts: Documentation and Interpretation of the Petroglyphs of Chichictara, using terrestrial laser scanning and image-based 3D modeling. In: Reindel M and Wagner G (eds) Miscellany at Springer, Berlin.

Hohmann, C. 2006. *Informe por el Instituto Nacional de Cultura sobre los trabajos del Projecto Arqueológico Nasca-Palpa*, Temporada de 2006.

Jacobsen, K. 2003**.** DEM Generation from Satellite Data. In: EARSeL (Hrsg.). Ghent : Millpress, 273–276.

Jacobsen, K., Passini, R. 2003. Comparison of QuickBird and IKONOS for the Generation of Orthoimages, ASPRS annual convention, Anchorage.

Jung, F., Paparoditis, N., Bretar, F., Maillet, G., 2005. Surface and terrain reconstruction from very high resolution imagery: Where are we now? New Strategies for European Remote Sensing, Oluic edition. Millpress, Rotterdam, ISBN 905966003X, pp. 429-436.

Kersten, Th., Baltsavias, E., Leiss, I., Schwarz, M. 2000. IKONOS-2 CARTERRA^{TM} Geo – Erste geometrische Genauigkeitsuntersuchungen in der Schweiz mit hochaufgelösten Satellitendaten, *VPK,* 8: 490 – 497.

Reindel, M. 2004. Wüstenzeichnungen und Wasserkulte: Geoglyphen und Siedlungsgeschichte in Palpa (Peru). In: *Expeditionen in vergessene Welten. 25 Jahre archäologische Forschungen in Amerika, Afrika und Asien.* AVA-Forschungen, Band 10. KAVA, Deutsches Archäologisches Institut, Bonn.

Fux, P. 2007. Das Petroglyphen-Projekt "Chichictara" in Palpa, Peru. Feldarbeiten im Jahr 2006 und Ausblick. SLSA Jahresbericht: 189-205.

Moseley, M. E. 1992. *The Incas and their Ancestors. The Archaeology of Peru*, Thames and Hudson, London.

Murra, J. 1972. El “Control Vertical” de un Máximo de Pisos Ecológicos en la Economía de las Sociedades Andinas. In: Murra J (ed), *Visita de la Provincia de Leon de Huanuco en 1562, Documentos para la historia y etnología de Huánuco y la Selva Central 2*, Universidad Nacional Hermilio Valdizan, Huánuco.

Poli, D., Zhang, L., Gruen, A. 2004. SPOT-5/HRS Stereo Images Orientation and Automated DSM Generation. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 35, Part B1: 421-432.

Poon, J., Fraser, C.S., Zhang, C. 2006. High-Resolution satellite imaging for digital surface models. Proceedings of ISPRS Ankara Workshop 'Topographic Mapping from Space (with special emphasis on small satellites)', Ankara, Turkey, Vol. 36, Part I/W41, 6 pages (on CD-ROM).

Reindel, M., Isla Cuadrado, J. 2004. Bericht über die Grabungskampagne 2003. SLSA Jahresbericht 2003: 137-156.

Sauerbier, M., Fasler, D., Della Casa, P., in press. Bronze Age landuse in the Central Alps: GIS-based investigation of influencing environmental and economic factors. Paper presented at the 36th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Budapest.

Silverman, H., Proulx, D.A., 2002. *The Nasca. The Peoples of America*, Blackwell Publishers, Malden, Oxford.

Tobler, W. 1991. Non-isotropic Geographic Modeling. In NCGIA Technical Report TR-93-1, Santa Barbara, USA.

Zhang, L., Gruen, A. 2004. Automatic DSM generation from linear array imagery data. *International Archives of Photogrammetry. Remote Sensing and Spatial Information Sciences*, XXXV. part B3. 128-133.

Multitemporal study of obsidian exploitation from Melka Kunture (Ethiopia) trough digital aerial photogrammetry and multispectral stereo-IKONOS II

R. Salvini[1], M. C. Salvi[1], A. Cartocci[1], S. Kozciak[1], R. Gallotti[2], M. Piperno[2]

1 University of Siena, Centre of Geotechnlogies , San Giovanni Valdarno (AR), 52027 Arezzo, Italy, salivinir@unisi.it, mcristinasalvi@unisi.it, alice.cartocci@unisi.it, kozciak@unisi.it

2 University of Rome "La Sapienza", Rome, Italy, m.piperno@tin.it, rosaliagallotti@yahoo.it

Keywords: Obsidian, digital photogrammetry, spectral signatures, multitemporal analysis.

ABSTRACT

Obsidian exploitation represents a leitmotiv of the Melka Kunture sequence during the last 1.7 Myr and the first example of Oldowan exploitation of this raw material.

The primary nearest obsidian source, Balchit, 7 km north from Melka Kunture, is a dome-flow dated to 4.37 ± 0.07 Myr and visible at the surface thanks to wide areas of dispersion and outcrops.

The proximity of primary and secondary Balchit obsidian sources, a high quality of raw material easily available in large quantity, represents an unique situation of the Oldowan and Acheulian East African sites, one of the few African geographical areas with high obsidian sources.

In order to evaluate the human impact on the multitemporal change detection of obsidian outcrops from aerial photos and IKONOS II imageries, respectively dated at the 1972 and 2006, the land use interpretation following the CORINE land cover Nomenclature have been produced.

The precise localization and the measure of their superficial extension have been possible due to the utilization of aerial photos and of couples of recent satellite stereoscopic IKONOS II imageries at a high spatial resolution (1 m). These last have been also utilized for the creation of the new topographic map of the area (100km2) at a scale of 1:10,000 and of the Digital Elevation Model.

The images, geometrically corrected and oriented thanks to Ground Control Points measured in site through a DGPS survey, have been radiometrically and spectrally corrected in order to permit the recognition of obsidian accumulation, in respect with ground truths collected during fieldworks.

The individuation of the obsidian outcrops and dispersion areas, has been done thanks to the high spatial resolution and the multispectral character of the satellite imageries. Image spectral and spatial enhancements have been applied to the scenes, while automatic classification of multispectral orthoikonos have been aided by spectral analysis carried out on obsidian samples by the FieldSpec Pro spectroradiometer, ranging in the 0.4-2.5 µm electromagnetic interval.

1 THE BALCHIT OBSIDIAN

The site of Balchit is located 7 km North of Melka Kunture, and it extends over 300 ha. The area is characterized by large concentrations of obsidian outcrops and debris dated to 4.37 ± 0.07 Myr (Poupeau *et al.*, 2004). It consists of a rhyolitic rock not crystallized while setting. The rock has a black colour with a very fine fluidity, however some *facies*, affected by pneumatolithic actions or by oxidations, have a green or red colour. This natural glass, easy to break, is compact and homogeneous, hard and poorly porous, vitreous or with a fine texture. The obsidian industry represents the essential component of lithic Middle Stone Age and Late Stone Age assemblages, while the most ancient evidences of its exploitation (0.7 Myr) are present in the Kenyan sites of Kilombe and Kariandusi (Chavaillon & Piperno, 2004).

The site was continuously occupied during the prehistoric times, and the exploitation of this obsidian source maybe occurred from the Late Stone Age till the modern times.

The lithic tool kit consists of large blades (figure 1), wide flakes, with plain or punctiform striking platforms, as well as cores, mainly prismatic and pyramidal ones.

Two are the kinds of occupation of this site. The first one go back to the palaeolithic and post-palaeolithic quarries, where blocks or fragments of obsidian outcrops were extracted in order to cut blades. The second one is due to the modern activity of the tanners, who selected the blades from the debris for scraping hides.

Some obsidian outcrops, included within volcanic sediments, are visible in the natural incisions, while three types of accumulation aspect are distinguishable: accumulation 60 m long and 50 cm thick, 10m long and 1 m thick, and more limited pit-like depressions, excavated to reach the veins in raw material searching.

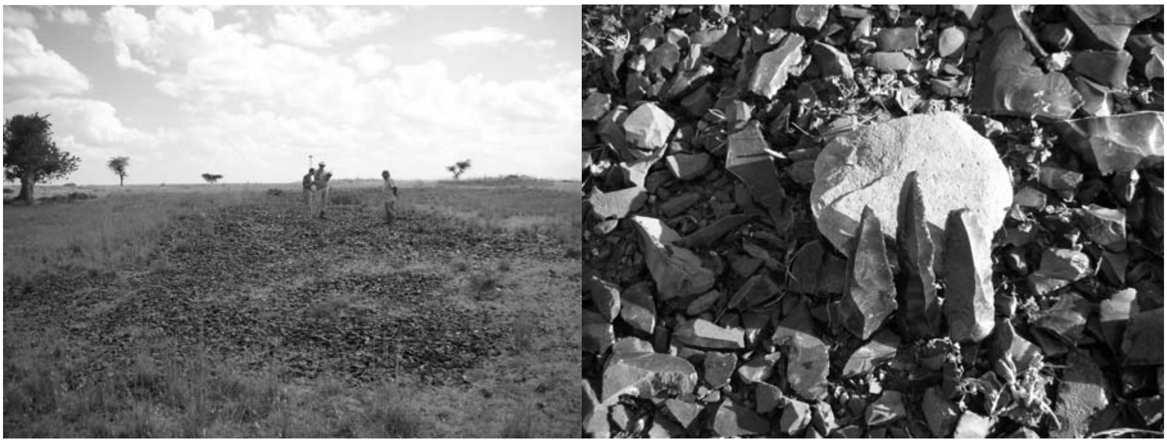


Figure 1. Obsidian accumulation in Balchit (left); obsidian blade samples (right).

2 ANALYSIS AND RESULTS

Being the extension of this site so significant and being Balchit's obsidian exported in far areas, measuring outcrop's localization and superficial extension is particularly important.

This goal was reached by means of several aerial photos at a nominal scale of 1:60,000 dated 1972 (Read *et al.*, 1973) and of two couples of satellite stereoscopic IKONOS II imageries (November 2006) at a high spatial resolution (1 m), in order also to evaluate possible multitemporal changes.

Two couples of *Standard Stereo* IKONOS II 1 m *Pansharpened* satellite imageries, covering an area of 102 km², have been purchased with the aim to study the archaeological area and to create, from the stereoscopic digital restitution, a new topographic map of Melka Kunture at a scale of 1: 10,000. For images orientation and aerial triangulation, together with the RPC (Rational Polynomial Coefficients), additional GCPs (Ground Control Points) collected by a DGPS survey have been utilized. In order to guarantee high accuracy and simultaneously appropriate acquisition timing, the measures have been recorded both in differential static modality and in Real Time Kynematic (RTK) way. The static modality, with a long acquisition time (up to three hours) has been referred to measure the BNP 267 trigonometrical station located few kilometres North-East to the archaeological site.

The satellite imageries have been radiometrically and spectrally enhanced in order to make easier the localization of obsidian accumulation in respect with ground truths collected during fieldwork.

From the restitution of the oriented stereopairs a DEM (Digital Elevation Model) was created; it was utilized, together with the exterior orientation parameters, for the elaboration of orthoimageries at spatial resolution of 1 m both for the years 1972 and 2006. Obsidian outcrops and dispersion areas individuation was obtained thanks to high spatial resolution and, for the satellite imageries, to multispectral character.

In order to quantify human impact on the outcrops and possible lost of obsidian sites during last 35 years, multitemporal change detection have been carried out from imageries in whole 8624 ha Balchit inquired area. The human impact, by means of remote sensing techniques, can be evaluated through multitemporal land use interpretation with the aim of identify and quantify land use transformations. The chosen codes derive from the CORINE Land Cover Nomenclature, 3 level (Heyman et alii, 1994), with widening to the 4 level, when possible. Such widening follows the guidelines for the compilation of the Management Planes of the SIC (Community Importance Sites) of the ETC-L.C. (European Topic Centre on CORINE Land Cover) and of the Italian Ministry of the Environment.

As the charts show (figure 2) two main trends are highlighted by land use modifications.

First a large increase of cultivated areas is pointed out: areas classified as 32 "Scrub and/or herbaceous vegetation associations" and 33 "Open spaces with little or no vegetation" in 1972 became in 2006 21 "Arable land" and 23 "Permanent crops" for a total amount of 4096 ha.

Secondly a significant urbanization process is highlighted: areas classified in 1972 as cultivated or uncultivated land (class 2 and 3) turned into class 11 "Urban fabric" in 2006 for a total amount of 1188 ha.

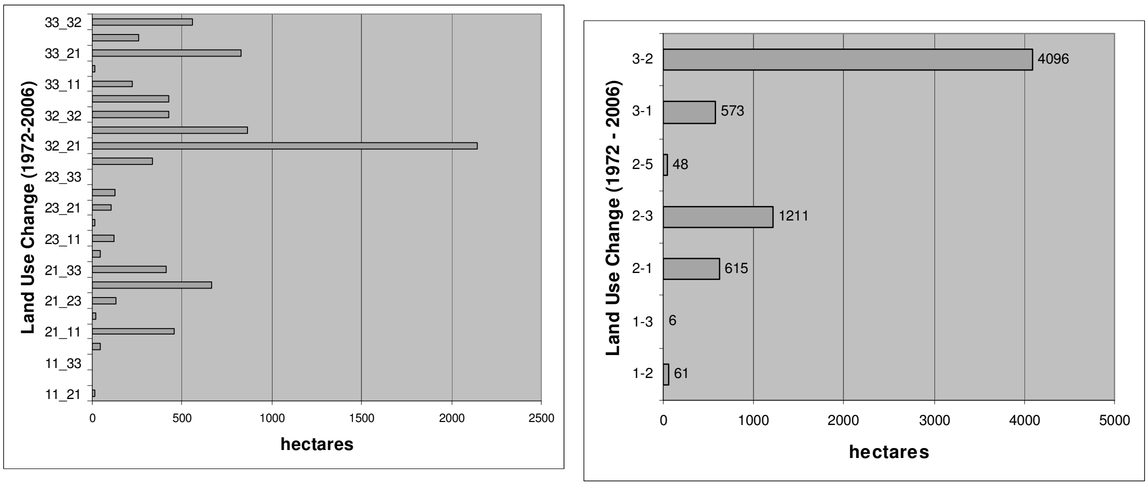


Figure 2. Land use changes. CORINE nomenclature level 2 (left) and level 1(right).

These changes testify an important social and economical development of the area potentially dangerous for known and unknown archaeological site related to obsidian sources.

In order to quantify the impact of this development, a multitemporal change detection about the obsidian outcrops extension and localization have been carried out.

An automatic supervised classification of multispectral orthoikonos have been aided by spectral analysis carried out on obsidian samples by means of the FieldSpec Pro spectroradiometer, ranging in the 0.4-2.5 µm electromagnetic interval (figure 3).

Areas of Interest to be used as reference signatures were identified by photointerpretation on previously known outcrop's areas in the spectrally corrected images, then a non parametric rule was applied for the classification of the whole area. Successively a median 3x3 filter was twice applied over classified image and areas smaller than 9 m^2 were discharged, in order to enhance model's reliability.

In November 2006 the total amount of obsidian outcrops, which represents main lithic sources and knapping areas, results to be 12.156 ha, while it was 11.584 ha in 1972.

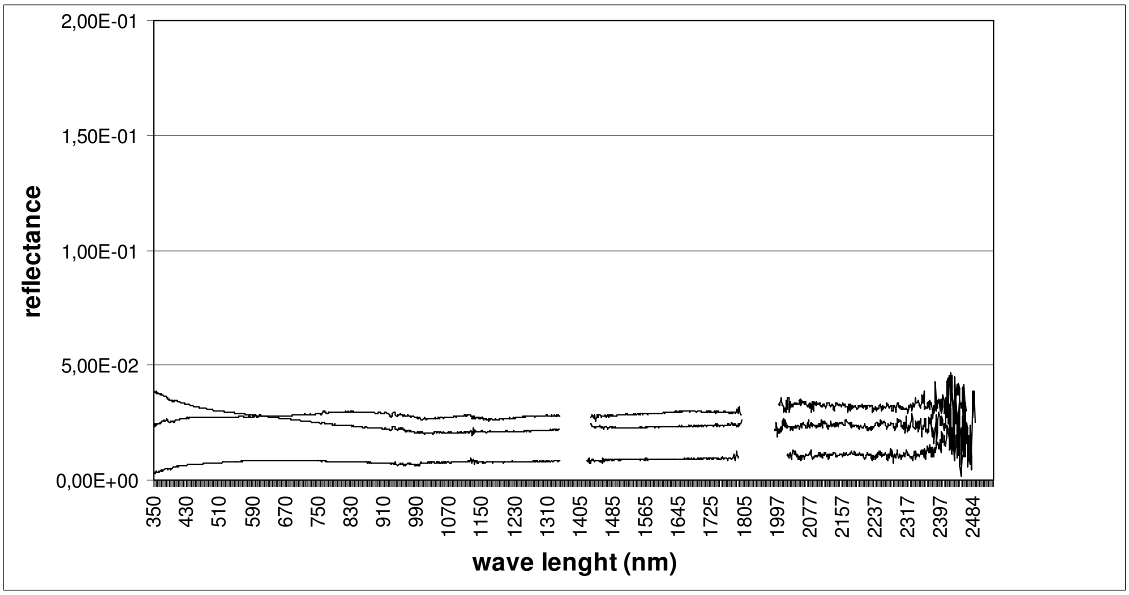


Figure 3. Spectral signatures on three Balchit obsidian samples.

3 CONCLUSIONS

Despite large land use changes, results about multitemporal extension of obsidian outcrops and accumulations show a non significant variation. Even if agricultural activities is rapidly increasing, probably the utilized tools for farming are still not invasive and they do not penetrate the soil up to remove and to scatter the obsidian rock.

Up to now agriculture do not represent a menace for archaeological site conservation; multitemporal land use analysis highlights urban development increase that, without adequate development and management policies, could be a threat for the archaeological site.

In order to achieve this goal the area of Balchit was already included in the archaeological park of Melka Kunture, proposed at UNESCO as future World Heritage Centre, in a way to permit safeguard and monitoring its cultural value.

4 REFERENCES

Carter, T., Poupeau, G., Bressy, C., Pearce, N.J.G. 2006. A new programme of obsidian characterization at Çatalhoyuk, Turkey, *Journal of Archaeological Science,* 33: 893-909.

Chavaillon, J., Piperno, M., (Eds) 2004. *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia*. Florence: Origines, Istituto Italiano di Preistoria e Protostoria.

Dial, G., Grodecki, J. 2003. Applications of Ikonos Imagery. American Society of Photogrammetry and Remote Sensing. In: *Proceedings of ASPRS Annual Meeting, 5-9 May*. Anchorage, Alaska.

Heymann Y., Steenmans, C., Croisille, G., Bossard, M. 1994. *CORINE land-cover project. Technical guide, European Commission Directorate General Environment, Nuclear Safety and Civil Protection. ECSC-EEC-EAEC*, Brussels.

Poupeau, G., Kieffer, G., Raynal, J.P., Milton, A., Delerue, S. 2004. Trace element geochemistry in Balchit obsidian (Upper Awash, Ethiopia). In: J. Chavaillon & M. Piperno (eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia*. Florence: Origines, Istituto Italiano di Preistoria e Protostoria., 103–110

Read, D., Fereday, D. L., Brown, R. 1973. Medium scale photogrammetric mapping at the directorate of overseas surveys. *Photogrammetric Record,* 7: 649–661.

Remote sensing and GIS data managing for archaeological maps: the case of Hierapolis of Phrygia (Turkey)

G. Scardozzi[1], A. Spanò[2]

1 CNR-IBAM, Italian National Research Council – Institute for Archaeological and Monumental Heritage, Strada per Monteroni c/o Campus Universitario, 73100 Lecce (Italy); g.scardozzi@ibam.cnr.it
2 *Polytechnic of Turin, Faculty of Architecture, Department of Scienze e Tecniche per i Processi di Insediamento, Viale Mattioli 39, 10122 Torino (Italy); antonia.spano@polito.it*

Keywords: large scale maps, GIS, data fusion, satellite remote sensing, archaeology.

ABSTRACT

Modern knowledge and development plans of environmental and archaeological sites are based on synergic studies and on the interpretation of archaeological evidences and their connections with landscape and territory. Carrying out project of ancient city map started some years ago as a cooperation of many groups working inside the Archaeological Italian Mission of Hierapolis. After some evolving phases (based on a continuous system of the map updating concerning archaeological and architectural evidences), during the last two years new spatial information, acquired from high resolution satellite images, topographical, archaeological and geophysical surveys, and enhanced methods of managing heterogeneous kind of data, have been accomplished. Now, a specific structure of topographical database collects archaeological, architectural and terrain data in a typical cartographic framework, and a large number of 1:1000 scale sheets, containing connected levels of information, compose the “Hierapolis of Phrygia Atlas”. GIS functionalities allow to manage and represent different nature data, about verifiable evidences on terrain, conjectured architectural structures or other kind of hypothesis based on a rebuilt morphology or standing out of archaeological elements. Relational database enables to archive temporal data, referred both to data origin than to the life or successive occupation of the objects that geometric features represent. Different data format and different temporal values, ordered by monument chronology, enable to represent different phases of human settlement and city life in specific thematic maps.

1 INTRODUCTION - TOPICS ON MAP PROJECT

Topographical survey activities aimed to found the large scale map of ancient city of Hierapolis have started in the late 1990s. The guide lines that characterized the production of such cartography at 1:1000 scale can be synthesized in following tips:

- Basic object, employed from the beginning, was combining information contents of a large scale plan of the town, based on archaeological and architectural hypotheses about the role of each building and of streets infrastructure in the city organization, assessing it to a rigorous outline of map generation (Spanò, 2001).
- The cartographic characterization of the product that was growing, has foreseen a strictly close range interpretation and data acquisition of ancient evidences, performed on ground; this purpose has defined the setting up of a hierarchical system of topographic networks including all ancient ruins in a common reference system, ensuring homogeneous accuracy of measures and final representation and a consequent suitability of map contents to requested quality level.
- The need of a aerial photogrammetric survey, purposed to document natural environment and terrain relief, had not been necessary any more when the Turkish Ministry of Culture provided to the Archaeological Italian Mission a traditional sheet map, produced by a photogrammetric flight dating back most excavations (last 1960s). The complete morphology of city territory has been extracted, harmonized with recent surveys and processed to digital format, to achieve an highly accurate DEM extended to urban and suburban area (more detailed information concerning the study of deformation retrieval of map sheets can be compared in Spanò, 2007).
- According to accustomed cartographic scheme concerning the separate processing of planimetric and altimetric models, the reference to global reference system UTM WGS84 and to national levelling network has been obtained by the mean of connecting topographic nets (known planimetric points and level points has been shared by General Command of Mapping, www.hgk.mil.tr, and by *Turkish Land Registry*).

2 DIFFERENT DATA ACQUISITION TECHNIQUES, SHARING INFORMATION AND DATA FUSION

Starting from 2001 campaign and the others immediately subsequent, excavations activities have been increased, and interchange bargains with interdisciplinary use of data acquisition and data processing technologies have been enhanced and develop to deepen the knowledge of the city.

Overhead, detailed survey of archaeological areas have been carried out with classical topographical technique (total station), in almost all case achieved by every team of the Mission on one's own, because the distribution of topographic networks established in the first phase of map set up has guarantee an efficient system of continuous updating of data collecting in the city reference system.

The most significant news in data acquisition and processing certainly is satellite remote sensing. After predictive analyses fulfilled on QuickBird scenes by the specialist of archaeological group (Scardozzi, 2007; D'Andria *et al.*, 2008, 25-30), an orthoprojection of the same QuickBird images has been performed by geomatic group with validate criteria aimed to retrieve data featured by congruent accuracy with map scale. This orthomap has established an extended archive of recent information about terrain evidences, and it has enabled to detect archaeological traces, verified through systematic archaeological surveys on terrain; vectorialization of archaeological traces and anomalies on orthomap was represent directly in common and shared reference system; other times, next to the outlining of particular marks, further archaeological surveys have been sighted with updating aim.

The interdisciplinary studies upon the city even conducted to integrate to the map the recent results of geophysical prospections, conveniently fulfilled in areas where other data or results of compared studies have pointed out the possible presence of submerged structures or anomalies to be investigated.

Such quality of data origin, of being made up of parts which are different from each other (detailed survey of ancient evidences, derived from archaeological excavation reading or from architectural interpretation joint together, acquired by classical topographic technique or detailed GPS survey or even with a photogrammetric plotting, extraction of terrain data from Turkish sheet map, satellite orthophoto plotting, or reading of archaeological traces on satellite images and further topographic survey, drawing of geophysical prospections) define the richness of map contents; in these last two years of conclusion of digital map and issuing of "Atlas", a great effort of generalization and conforming all thematic high scale representation, has been fulfilled in order to harmonize and make homogeneous the quality standards on the whole territory of city (positional accuracy, completeness, data consistency) (figure 1).

3 SPATIAL DATABASE ORGANIZATION AND DATA REPRESENTATION

The interdisciplinary of the interpretation of the portions of the city in its complex and the disparity of the origin of the dates brought that the cartography doesn't represent only the actual situation objectively visible but it reflects a cognitive range that become more complex and rich by the hypotheses today brought forward. In this way, the representation of the city and of its architectonic organisms relates at the same time the objective situation of what is conserved, the reconstruction of the characteristic of the build that with a good certainty are hold as note, and it is possible to image the hypotheses about the shape on the available database.

By the management potentiality of the GIS working environment, the decisive turning-point impressed to the cartography was its conversion in a topographic and spatial database. It was started the conversion in a dates and object structure, able to the related organization of the database that, about the territory and the modern anthropization, inspired to the guide lines expressed by the international organisms the are involved to define the standard of the spatial information (*OpenGis Consortium*).

About the ancient buildings, it was necessary to study a method ad hoc of definition of the geometric entity that represented the reality, to report exactly as the note range as the hypothetic one. Besides, although in the GIS working environment are shared in some portions of the city represented by an architectonic database structure, it was realized, above all to the publication of the "Atlas", a representation that evenly report an average reading level between the urban scale and the build one.

The today descriptive attributes implemented and related to the geometric entity, more than identify each architectonic complex of the ancient city (the legend in the urban square report seventy different structures localizable, except the network of the *stenopoi*), more than report the date origin that identified the level of certainty with which it is rendered, identifying in a schematic way the temporal stratification of the structures, the portions of the first settlement and the successive integrations

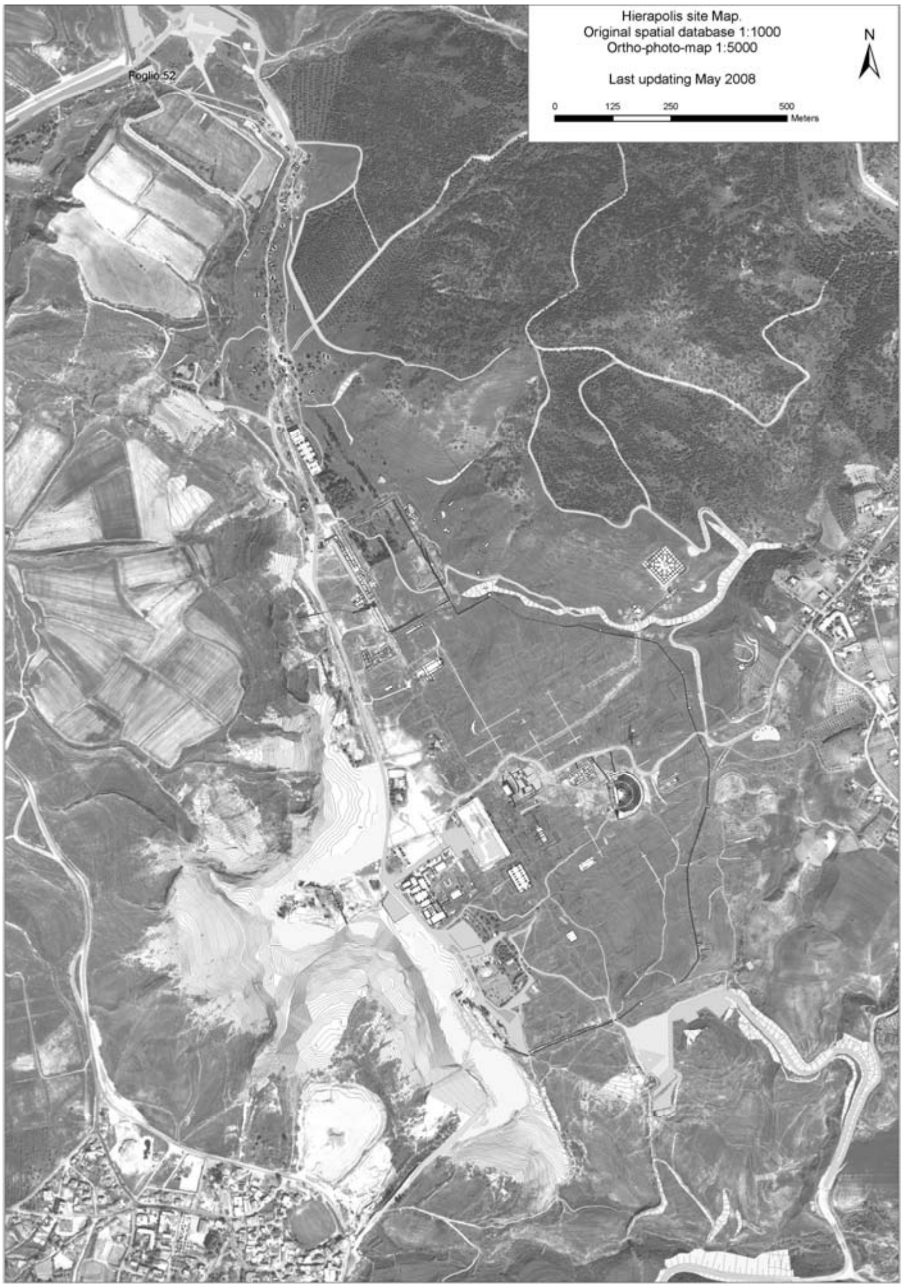


Figure 1. Digital map superimposed on satellite orthomap

4 ACCOMPLISHING THEMATIC MAPS BY GIS TOOLS

Archaeological studies had identified four subsequent steps of the historical development of the city: from its foundation in the 3rd century BC until the devastating earthquake in 60 AD, from the Flavian period until the earthquake in the middle of the 4th century AD, the proto-Byzantine period, and a fourth chronological phase after a destructive earthquake in the middle of the 7th century AD, when Hierapolis went into decline (D'Andria *et al.*, 2008, 31-47). The representation of the different steps of the urban settlement of the city, by the management of the numeric cartography in the GIS working environment, corresponds, exactly like the sheets of the "Atlas", to a specific and aimed thematization of data, originated by the attributes correlation with descriptive nature about the different length and human attend of the build structures.

The objective of the realization of thematic maps that shows the spatial distribution of the phenomena that evolved during the time is one of the typical aim of the GIS working environment; the database of the city of Hierapolis has been projected and utilized in order that an analysis spatial and temporal set allows to satisfy this demand. Generally, each phase map is realized by a query that bind the visualization at the build structures associated to temporal attributes that falls within the individuated temporal limits (figure 2). Obviously that base tip can't be applied in a linear way because the city is a pulsing organism: the first four schematic phase maps were realized with the identification of the built structures that will be build in a specific temporal moment and keep their general shape unchanged in time, those that in successive phases are interested by deep transformations, those that were simply left, those that left the first/native function were assigned to a new one.

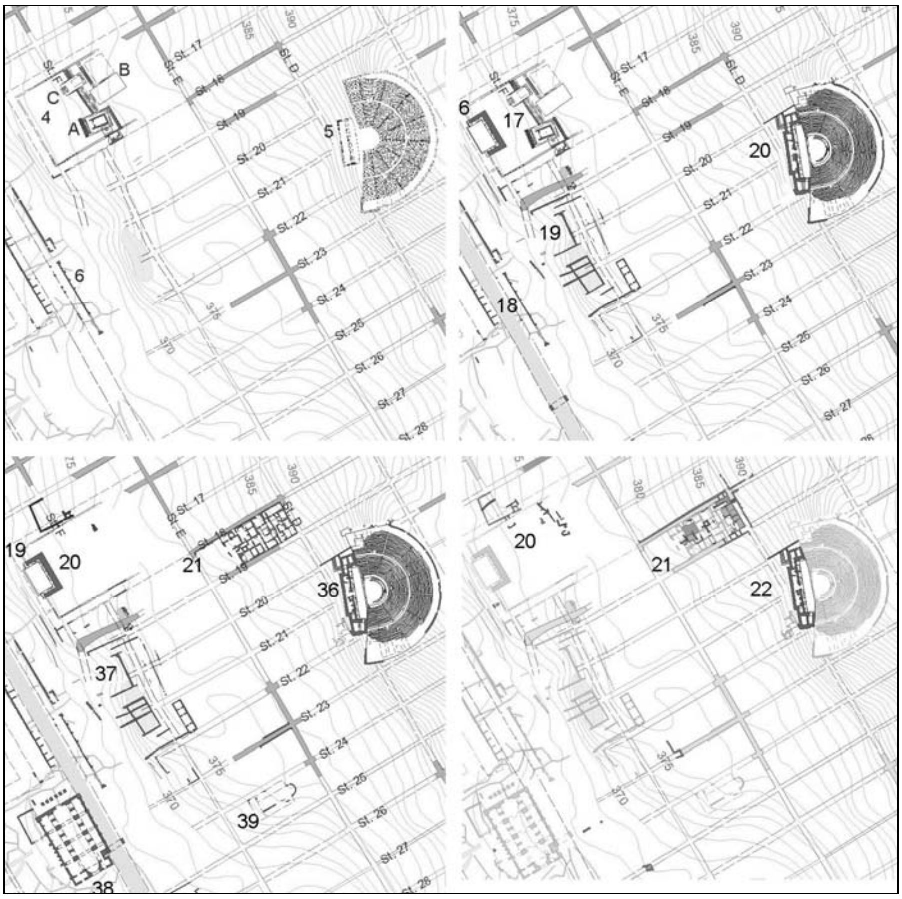


Figure 2. City growth and buildings dismission in the thematic phases maps.

5 ACKNOLEGMENTS

The authors wish to thank Prof. Francesco D'Andria, director of the Italian Archeological Mission in Hierapolis of Phrygia, to be involved in this huge research.

6 REFERENCES

D'Andria, F., Scardozzi, G., Spanò, A. 2008, *Atlante di Hierapolis di Frigia*, Istanbul.

Scardozzi, G. 2007. L'urbanistica di Hierapolis di Frigia: ricerche topografiche, immagini satellitari e fotografie aeree, *Archeologia Aerea. Studi di Aerotopografia Archeologica*, II: 83-134.

Spanò, A. 2002. Le ragioni dell'intervento di natura topografica a Hierapolis, in De Bernardi Ferrero D. (a cura di), *Saggi in onore di Paolo Verzone*, (Hierapolis. Scavi e ricerche, IV), Roma, 233-261.

Spanò, A. 2007. Rilievo metrico, cartografia numerica e GIS, in D'Andria F., Caggia M.P. (a cura di) 2007, *Hierapolis di Frigia, I. Le attività delle campagne di scavo e restauro 2000-2003*, Istanbul.

http://www.opengeospatial.org/

Integration of geomatics techniques for the digital documentation of heritage areas

S. Campana[1], M. Sordini[1], F. Remondino[2,3]

1 Dept. Archaeology & History of Arts, Landscape Archaeology - University of Siena, Italy. E-mail: campana@unisi.it, sordini@lapetlab.it - www.lapetlab.it

2 Institute of Geodesy and Photogrammetry - ETH Zurich, Switzerland, fabior@ethz.ch - www.photogrammetry.ethz.ch

3 Centre for Scientific and Technological Research - Bruno Kessler Foundation, Trento, Italy - www.fbk.eu

Keywords: 3D Modeling, Photogrammetry, Excavation, Laser Scanning, Multi-resolution

ABSTRACT: Prompted by the increasing requirement for the fast but precise and detailed digital documentation of archaeological excavations, site and heritage artifacts, we report the latest geomatics trend in integrating different data at different resolution to capture all the information required for a complete 3D documentation of heritage sites and archaeological excavations. Our case studies focus on two Tuscan archaeological sites of late antique-early medieval and roman time, located in the province of Siena, Italy. We report about the available geomatics techniques and methodologies to digitally document large sites, fulfil all the archaeological needs and exploit all the potentialities of the new digital surveying techniques.

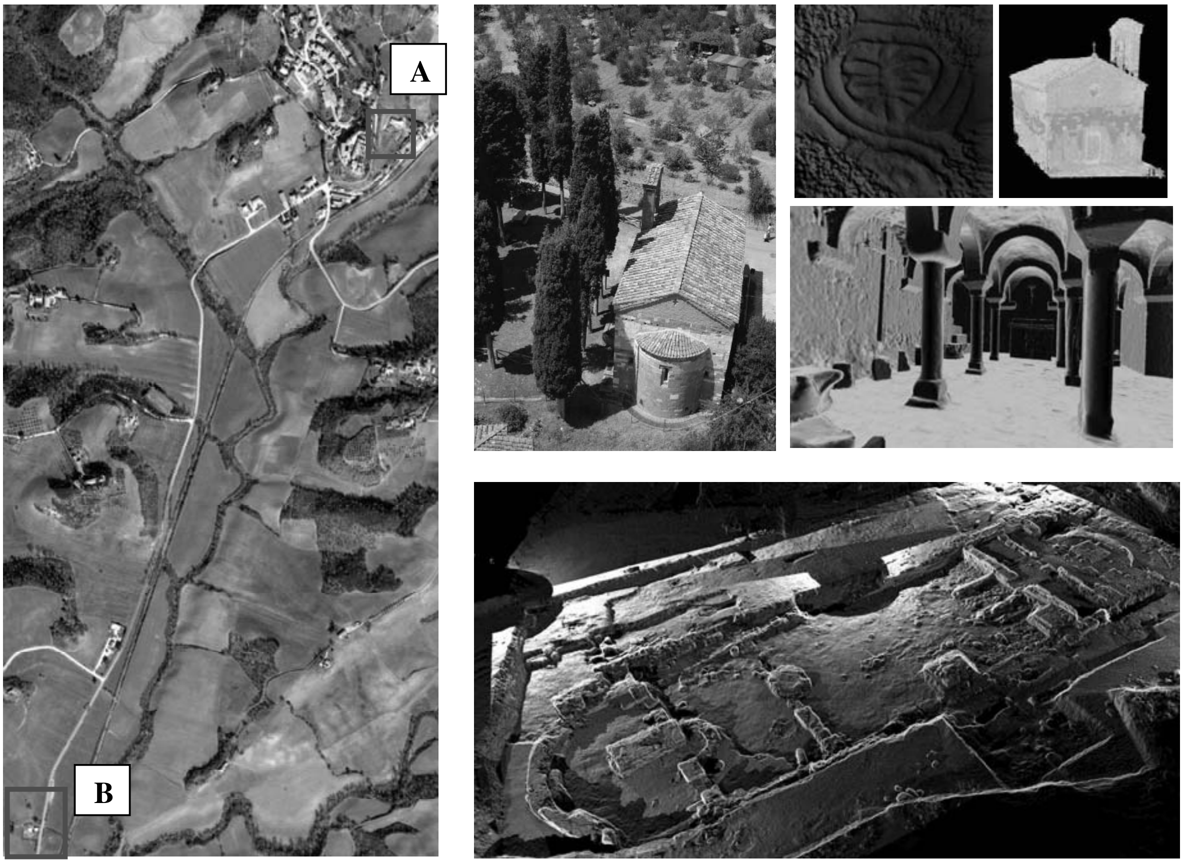


Figure 1: A Quickbird image over the area of interest with highlighted the church in S.Giovanni Valdarno (A) and the excavation of Pava (B). The church was modeled using a ToF scanner and digital images for some details. The excavation was documented with oblique aerial images (derived DSM at 5 cm resolution) and a ToF scanner.

1 INTRODUCTION

In archaeology the systematic and well-judged use of geomatics techniques for documentation and digital conservation purposes is a relatively recent innovation, not yet applied on a regular basis for a variety of reasons: the perceived ‘high cost’ of 3D, the difficulties in achieving good 3D models, the difficulty of integrating 3D worlds with other 2D data and traditional documentations and the perception that 3D is only an additional ‘aesthetic’ factor. Nowadays the most common geomatics techniques used for 3D documentation, reconstruction and interpretation process in the archaeological field are based on image data (e.g. photogrammetry) (Remondino & El-Hakim, 2006) or range data (e.g. active sensors such as laser scanners) (Blais, 2004). Both approaches have their own advantages and disadvantages and generally the choice between them is made according to the budget, project size and goal, required degree of detail and experience of the working team.

2 GEOMATICS TECHNOLOGIES FOR ARCHAEOLOGICAL NEEDS

Nowadays we have at our disposal a wide amount of geomatics data acquisition tools for cultural heritage recording and documentation (Figure 2): middle and high resolution satellite imagery (SPOT, IKONOS, Quickbird, OrbView, IRS, ASTER, Landsat, etc), large format and linear array digital aerial cameras (DMC, ULTRACAM, ADS40, etc), space and aerial radar platforms (Radarsat, ERS, AirSAR), LiDAR range sensors, UAVs (e.g. model helicopters) with consumer digital cameras onboard, panoramic linear sensors as well as still video cameras, camcorders or even mobile phones. Moreover GPS and INS/IMU systems allow precise localization and navigation. Along with the availability of this great variety of digital data, new software has been developed in the last decade and many automated procedures are now commercially available, in particular for image orientation and surface model generation (DTM or DSM) or feature extraction from range data. Furthermore Geographic Information System (GIS) tools provide many new functionalities for 3D data administration and analysis while visualization and animation software packages are nowadays more affordable at better functionality and lower cost.

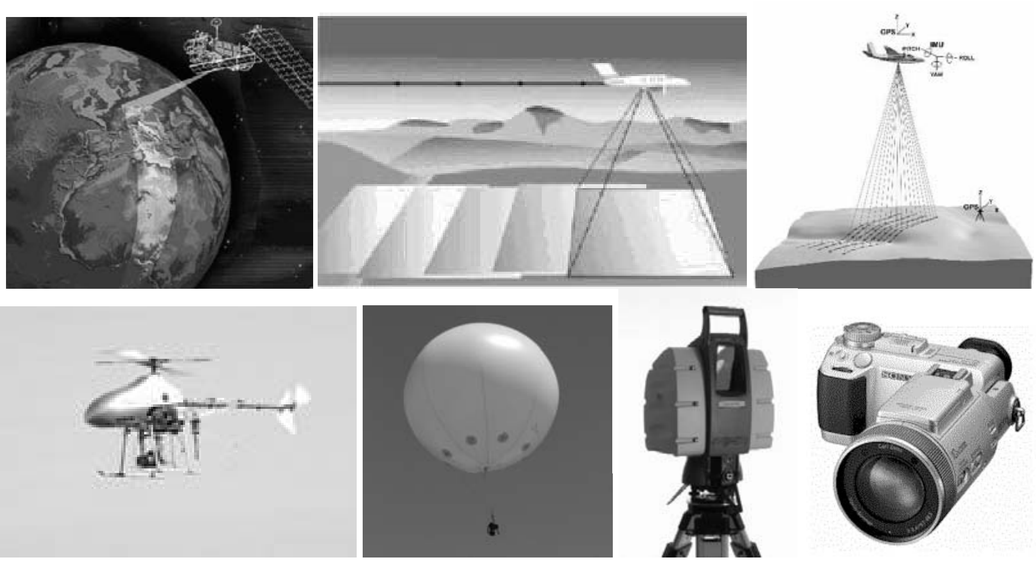


Figure 2: Different platforms (satellite, airborne, UAV, balloon, terrestrial) and instruments (cameras, range sensors) providing data that can be processed to derive 3D models at different scale.

Following (Lambers & Remondino, 2007), we can identify three scales of archaeological research where geomatics techniques and methodologies can be applied (Table 1):

(1) the *regional scale*, to record the topography of archaeological landscapes and to detect and map archaeological features. While excavations tend to focus on important sites and their graves, architecture or artefacts, these remains can only be understood in their cultural, socio-economic and environmental framework. This requires a thorough study of the site's hinterland including its network of other sites with domestic, religious, economic, and other functions, as well as its topography, natural resources, and paleoclimatic conditions. There are thus two tasks for optical 3D and related measurement techniques in regional archaeological research: (1) the recording and modelling of the topography and (2) the detection and mapping of archaeological sites and features. Spaceborne and airborne sensors provide suitable data for these tasks.

(2) the *local scale*, to record smaller sites and their architecture and the excavated material remains. Regardless of its actual size, function and duration of occupation, the material remains of an activity at a defined lo-

cation hold important clues about the social, cultural, technological and ideological background of the ancient inhabitants.

(3) the *object scale*, to record artifacts and excavated finds. Artefacts recovered during excavations or stored in museum deposits are the material expression of cultural, socioeconomic, and technological concepts shared by their creators. A thorough recording of stone or metal tools, worked bones, ceramic vessels, sculptures, and other pieces of ancient craftsmanship is not only a prerequisite for typological and chronological studies, but also for investigations into the exchange of goods and ideas, iconography, technology, and a variety of other topics. While artefacts are until now usually recorded in 2D through drawings and photographs, 3D recording literally adds a new dimension to archaeological studies at the object scale as it provides additional information that enables new kinds of investigation, e.g. morphological comparisons, 3D fragment fitting etc. Furthermore, virtual replicas of artefacts enable web-based exhibition and facilitate the production of physical replicas, thus helping to preserve the original artefacts.

Archaeological research	**Object of interest**	**Available geomatics sensors and data**		
Regional scale	• Landscape • Topography • Sites	➢ Middle and high-resolution satellite imagery ➢ Small scale aerial images ➢ Radar and LiDAR ➢ GPS	**Geometric resolution** ↓	**Level of Detail** ↓
Local scale	• Sites • Architectures • Excavation layers	➢ Large scale aerial images ➢ Radar and LiDAR ➢ ToF range sensors ➢ Terrestrial images ➢ Total stations ➢ GPS		
Object scale	• Excavated artifacts • Museum objects	➢ Terrestrial images ➢ Triangulation-based range sensors ➢ GPS		

Table 1: Scales of the archaeological research and documentation and related geomatics sensors and data for the 3D digital documentation. From regional to object scale, the acquired geometric resolution and achievable level of detail are gradually increasing and improving.

Having all the aforementioned data acquisition tools at our disposal, the great challenge is to integrate the different data to achieve a multi-resolution documentation of large and complex site. Multi-resolution data are nowadays the base of different geospatial databases and visualization repositories. Probably the best and most known examples are given by Google Earth or Microsoft Virtual Earth. Data span from hundreds meters resolution (both in geometry and texture) down to few decimeters (only in texture). The user can browse through the low-resolution geospatial information and get, when necessary, high-resolution and detailed imagery, often linked to other 2D/3D information (text, images, city models, etc).

For the 3D archaeological survey of large excavation areas or heritage sites, a similar approach should be selected. A top-bottom methodology should be employed, starting from traditional satellite/aerial images and reaching higher resolution and geometric details through range data and terrestrial images. As the 3D documentation of both landscape and artifacts or excavated finds requires data with very different resolution, their registration and integration must be carefully carried out to produce seamless and realistic 3D results.

3 3D DOCUMENTATION OF ARCHAEOLOGICAL EXCAVATION AND HISTORICAL BUILDING

We have been working since some years in the heritage area of Pava and S.Giovanni Valdarno (Siena, Italy). The excavation of Pava (Campana & Francovich, 2005) was documented using satellite imagery, oblique aerial images (figure 3), balloon and model helicopter data as well as ToF laser scanning (figure 1). Each sensor and dataset is providing information useful in the different documentation's level of details and their integration is showing very successful results.

Beside the exaction area, a Romanesque church was also digitally documented. The church with its crypt (figure 1) was surveyed with a ToF scanner as well as digital images to picture unreachable areas for the scanner (e.g. the roof), acquire the texture for photo-realistic results and model in high resolution some details. Also in this case, the integration between the different data sources was essential to have the complete geometric information of the heritage.

The next step of the work is the integration of all the derived 3D models in a unique repository and the linking with other archaeological (2D) information and the existing database.

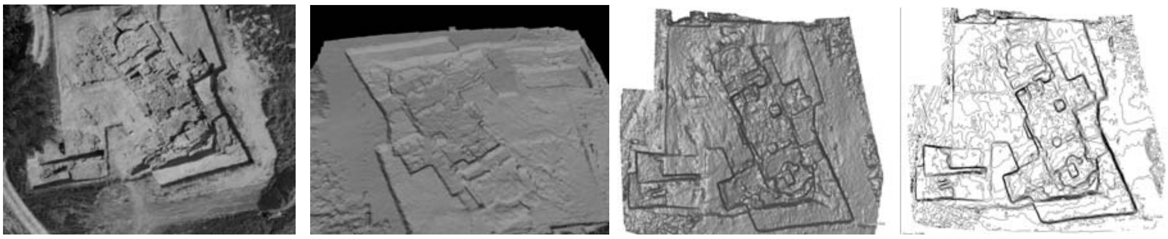


Figure 3: The excavation area of Pava and the derived DSM from oblique aerial images.

4 CONCLUSIONS

The returns in recent decades of archaeological research from the use of 3D digital documentation and representation, in terms of scientific investigation, are relatively disappointing, bearing in mind the possibilities offered nowadays by newly developed software and hardware. The use of 3D images has typically been focused on the production of finished reconstructions and not on the potential contribution to scientific interpretation. It is our contention that 3D recording and modelling should constitute a bridge between ‘data, knowledge and communication’. It is remarkable that archaeological excavations using 3D technologies in their data acquisition and reconstruction are still so few. As a result the documentation process is fragmented into many different ontologies, often lacking the necessary or desirable 3D information.

In this contribution we have demonstrated how accurate and detailed 3D results can be readily derived from the integration of the multiple available geomatics tools. It is well known that active sensors facilitate the relatively easy and rapid acquisition of large quantities of 3D information, but the cost of the equipment and related problems of transportation, along with the complexity of the subsequent data management, raise serious problems of practicality in many archaeological situations. Therefore, we suggest, as alternative, the appropriate use of image-processing algorithms or integrating methodologies, to create realistic 3D models, with good geometric detail. Images acquired with low-cost digital cameras (or even mobile phones) in the hands of non-specialist research workers can give very satisfactory results and allow satisfactory results for the daily archaeological 3D documentation.

5 REFERENCES

Blais, F., 2004. A review of 20 years of range sensors development. *Journal of Electronic Imaging*, 13(1): 231-240.

Campana, S., Francovich, R. 2005. *Seeing the Unseen. Buried Archaeological Landscapes in Tuscany*, Taylor & Francis, The Netherlands, pp.67-76

Lambers, K., Remondino, F., 2007. Optical 3D measurement techniques in archaeology: recent developments and applications. *Proc. of CAA 2007* Conference, Berlin, Germany (in press).

Remondino, F., El-Hakim, S., 2006. Image-based 3D modelling: a review. *Photogrammetric Record*, 21(115): 269-291.

Use of declassified panoramic satellite imagery for change detection in an area of archaeological interest

G. Bitelli, V. Alena Girelli, S. Neri, L. Vittuari

DISTART Dept. – University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy, E-mail: (gabriele.bitelli;valentina.girelli;luca.vittuari)@mail.ing.unibo.it

Keywords: Panoramic images, Remote Sensing, Digital Photogrammetry, Change Detection

ABSTRACT.

In the framework of a multidisciplinary research carried out at the Tilmen Höyük archaeological site, in South-Eastern Turkey, and its surrounding region, remote sensing data are adopted for characterization of the area and of its evolution in time.

In order to perform some change detection analysis, some old declassified satellite images are used coming from the Corona program, the first U.S. operational space photo reconnaissance project, operating in the period 1960-1972. The images are of panoramic type, affected by severe distortion; a high resolution scanned copy has been processed using a digital photogrammetric workstation in order to produce metric products of acceptable quality for mapping purposes.

In the paper some specific problems of these cameras are presented, together with the procedures adopted for image orientation and data processing. External orientation and digital triangulation were limited by the lack of well distributed and reliable ground control points, but the results are in any case of interest as they allow the integration, on a common cartographic reference base, with current imagery (from medium to very high geometrical resolution) to perform automatic or manual procedures of comparison and change analysis.

1 THE CORONA PROJECT

The term “Corona” indicates a secret U.S. project supported by the Central Intelligence Agency (CIA) and by President Eisenhower and started in 1958, with the aim of launching in orbit satellite able to photograph the Earth, in particular in order to monitorate the military and nuclear progresses of Russia and Middle East.

The first satellite was launched the 29th of February 1959, but the first successful mission was in 1960; the project ended in 1972, after 144 missions. During the programme various systems were used, with characteristics in continuous evolution, especially in terms of ground coverage and resolution. The early systems (KH-1, KH-2, KH-3 and KH-6) carried out a single panoramic camera or a single frame camera (KH-5), while the later systems (KH-4, KH-4A and KH-4B) carried out two panoramic cameras with 30 degrees separation angle, in order to acquire stereo coverage (NRO Data Book, 1967). In the end, CORONA acquired over 800000 photographs with a total coverage of at least from 1.5 to 2 million km^2 of the Earth’s surface (McDonald, 1995).

In 1994 the U.S. government approved the development and deployment of ‘down to one metre’ ground resolution sensors for commercial satellites, so from the 1995 Corona images are DISP images (Declassified Intelligence Satellite Photographs), available for civil purposes.

The agency that practically sells these images is the United States Geological Survey (U.S.G.S.); from the Earth Resources Observation System (E.R.O.S.) Data Center web site is available the on-line shopping of negatives, slides, prints and digital files of the images; the original film and technical mission-related documents are instead maintained by the National Archives and Records Administration (N.A.R.A.) and are available only after a standard procedure (Galiatsasos, 2004).

1.1 *The Corona panoramic images*

In the Corona program panoramic cameras were chosen to obtain at the same time high geometric resolution and a large swath value, two fundamental characteristics for photo-reconnaissance from space.

The acquisition principle is easy: the film is mounted on a half-cylinder surface and the camera moves in a direction transversal to the way of flight; a slit in front of the film allows the exposure. Table 1 summarizes some technical data available about Corona systems and related images.

Due to the acquisition mode, Corona images present several types of image distortions which are not present in the normal metric frame camera and caused by three factors: the film mounting device (panoramic distortion), the motion of the platform as the lens scans (scan positional distortion), the translation of the film surface due to Image Motion Compensation device (IMC distortion). Considering these distortions it is possible to express modified collinearity equations that describes in an analytical form the panoramic image acquisition (Sohn et al., 2004).

System	**KH-1-4**	**KH-4A**	**KH-4B**	**KH-5**	**KH-6**
Camera type	Panoramic	Panoramic	Panoramic	Frame	Panoramic
Film width	70 mm	70 mm	70 mm	12.7 mm	12.7 mm
Frame format (mm × mm)	5.54 × 75.69	5.54 × 75.69	5.54 × 75.69	11.43 ×11.43	11.43 × 63.5
Focal length (mm)	60.96	60.96	60.96	7.62	167.64
Best ground resolution (m)	7.6	2.7	1.8	14	1.8
Nominal altitude (km)	170 to 460	185	150	320	170
Nominal photo scale	1:275000 to 1:760000	1:305000	1:247500	1:4250000	1:100000
Nominal ground coverage (km)	15 × 290 to 42 × 580	17 × 232	14 × 188	483 × 483	12 × 64

Table 1. Characteristics of Corona systems (from USGS web page).

Some authors propose other approaches that consider time-dependent Exterior Orientation Parameters or terrain-dependent Rational Function Models; an alternative method, named IEFP (Instantaneous Equivalent Frame Photograph), reduces panoramic images to frame images acquired with the same inclination and focal length (Case, 1967).

In any case it is important to underline that only a precise knowledge of all acquisition geometry parameters permits the rigorous panoramic camera model approach; however, as mentioned before, the ephemeris data are not available or not easily accessible and so it is necessary to use some best approximation data taken from published sources and to calculate the rest, by means of an adequate number of ground control points of good quality.

2 THE ARCHAEOLOGICAL SITE OF TILMEN HÖYÜK

The Joint Italian-Turkish Archaeological Mission at Tilmen Höyük site started in 2003 and it is conducted by the Archaeology Department of Bologna University in collaboration with Istanbul University and Gaziantep Museum; the DISTART Department cooperates on this project since 2005, performing a multi-technique multi-scale surveying approach (Bitelli *et al.*, 2006), with the aim to support also all the research carried out by the different research groups (archaeological, geophysical, environmental, etc…).

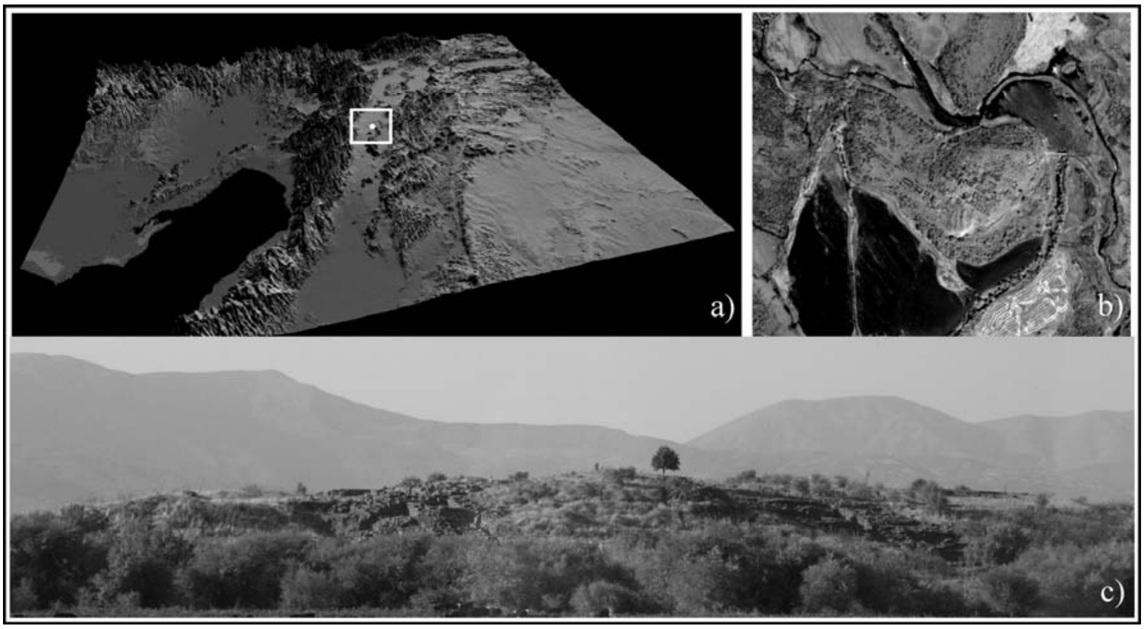


Figure 1. Location of the archaeological site of Tilmen Höyük depicted on SRTM Digital Terrain Model (a) and on a QuickBird satellite image (b); a picture of the site (c).

The site is an ancient settlement, located in South-Eastern Turkey (figure 1) within Gaziantep region, with its major phase dating back to the 2nd mill. BC, with a continuous occupation from the Late Chalcolithic through the end of the Bronze Age; it represents one of the most significant urban centres both to reconstruct contacts between Syria and Anatolia and to investigate characteristics and spatial organization of 2nd millennium BC capitals (Marchetti 2006a; 2006b).

Besides the researches on the archaeological site, a larger survey in the Islahiye valley is scheduled by the Joint Expedition and, thus, the availability of a large image database, spanning time and space, is essential for that project.

3 ORTHOPHOTO GENERATION BY CORONA IMAGES

The image used for orthophoto generation belongs to KH-4A Corona system, acquired on 3 March 1968; the approximate image footprint together with some metadata are available on USGS web site. The digital image provided by USGS has been produced by means of a photogrammetric scanner with a geometric resolution of 7 µm; the image, because of the large film format, has been divided in 4 single files with a reduced longitudinal overlap (figure 2).

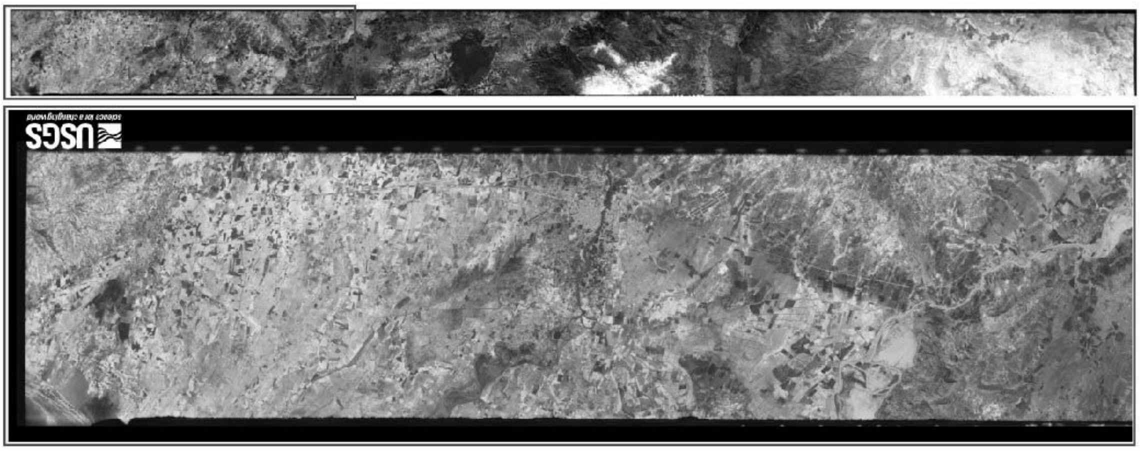


Figure 2. Complete Corona image and below one of the single digital file created by scanning operation.

Image processing was performed using the Digital Photogrammetric WorkStation Socet Set v.5.4.0. Socet Set includes a specific tool for panoramic frame import that creates a model with compensation for sensor movement. It's important to underline that this software permits a rigorous panoramic camera model approach, but this method needs the knowledge of ephemeris and acquisition technical data, not always easily available; using approximate value known from reference fonts involves consequently the requirement of good ground data, in order to apply a global triangulation process to solve for inner and exterior parameters.

For a first test, the coordinates of 50 Ground Control Points (GCPs) were derived from Google Earth system. Some problems were of course encountered in the individuation of the points because of various factors: the large changes suffered by the territory from 1968 till today, the non-uniformity in terms of image georeferentiation properties of Google Earth database (in particular considering the wide area covered by a Corona image) and the morphology of the territory, characterized by mountains and wooded area, that makes difficult a homogeneous distribution of points. The generated orthophoto, produced using as DEM the SRTM (Shuttle Radar Topography Mission) dataset, is shown in figure 3.

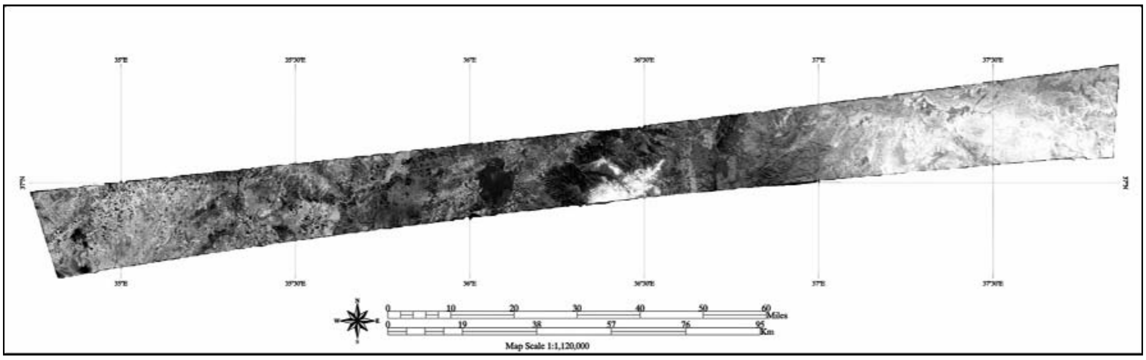


Figure 3. Orthophoto of Corona image (Ground Sample Distance=10m; geographic coordinates WGS84).

The residuals on the ground control points after the triangulation phase achieved an average value of about

10 m in planimetry and 5 m in height; nevertheless the analysis on the coordinates of some check points underlined the non-homogeneity in the orthophoto accuracy.

The processing on the image portion including Tilmen Höyük site has therefore been repeated, using as ground data for image orientation 15 points derived from medium scale cartographic maps and from high and moderate resolution georeferenced satellite imagery (QuickBird, ASTER). In this case, as expected, the achieved accuracy was better than the previous; the analysis on some check points coordinates evidenced residuals in the order of 5 meters. This fact demonstrates, as said before, the need of good ground data for these images. The generated orthophoto for this image portion is shown in figure 4.

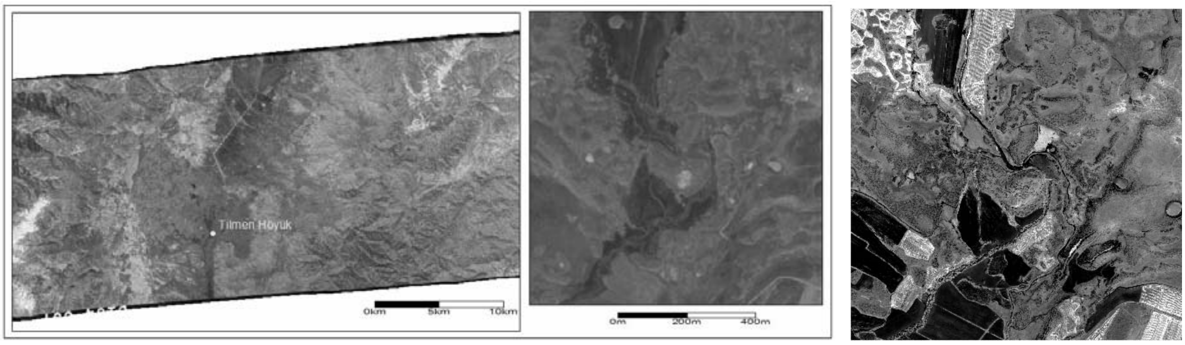


Figure 4. Left: ortophoto of a portion of Corona image and detail for the area surrounding Tilmen Höyük site (GSD=5m). Right: the same area depicted on the orthophoto generated from QuickBird panchromatic imagery (2003).

4 CONCLUSIONS

The use of declassified panoramic satellite imagery, after specific digital photogrammetric processing, has permitted to obtain a metric georeferenced database essential to perform medium-term change detection image analysis procedures. A first visual inspection of the results clearly shows remarkable changes intervened in the area in the last 40 years; a more rigorous change detection procedure is in progress in a hybrid GIS – Remote Sensing software environment using different kind of satellite imagery (e.g. Landsat, ASTER, QuickBird) and will permit to delineate modifications occurred in land cover, land use and morphological characters.

5 REFERENCE

Bitelli, G., Girelli, V.A., Remondino, F., Vittuari, L. 2006. Surface modelling of complex archaeological structures by digital close-range Photogrammetry. *British Archaeological Reports Internat. Series*, 1568: 321-326, Oxford.

Case, J.B.1967. The analytical reduction of panoramic and strip photography, *Photogrammetria* : 127-141.

Galiatsatos, N. 2004. *Assessment of the CORONA Series of Satellite Imagery for Landscape Archaeology: a Case Study for the Orontes Valley, Syria.* Durham University, PhD Thesis.

Marchetti, N. 2006a. Middle Bronze Age Public Architecture at Tilmen Höyük and the Architectural Tradition of Old Syrian Palaces. In F. Baffi, R. Dolce, S. Mazzoni and F. Pinnock (edd.), ina kibrat erbetti. *Studi di Archeologia orientale dedicati a Paolo Matthiae*, Università La Sapienza, Roma, pp. 275-308.

Marchetti, N. 2006b. New Results on Middle Bronze Age Urbanism in South-Eastern Anatolia: The 2004 Campaign at Tilmen Höyük, in *Colloquium Anatolicum* 5 : 199-211.

McDonald, R.A. 1995. CORONA: Success for Space Reconnaissance, A look into the Cold War, and a Revolution for Intelligence. *Photogrammetric Engineering and Remote Sensing*, 61 (6) : 689-720.

NRO (National Reconnaissaince Office), (1967). *The KH-4B Camera System.*

Sohn, H.G., Kim, G., Yom, J. 2004. Mathematical modelling of historical reconnaissance CORONA KH-4B imagery, *The Photogrammetric Record*, 19 (105) : 51-66.

6 ACKNOWLEDGEMENTS

The authors would like to thank all the members of the Archaeological Expedition to Turkey of the University of Bologna, in particular its Director Nicolò Marchetti, for the fruitful collaboration and for supplying the images.

Multiple sensors and multi-resolution data for large scale mapping and artifacts documentation

F. Chiabrando, A. Spanò

Polytechnic of Turin, Faculty of Architecture, Department of Scienze e Tecniche per i Processi di Insediamento, Viale Mattioli 39, 10122 Torino, Italy. E-mail: antonia.spano, filiberto.chiabrando@polito.it

Keywords: orthophoto, mapping, non metric cameras, satellite imagery, GIS, Archaeology

ABSTRACT.

In the framework of joint projects promoted by Archaeological Italian Mission in Hierapolis of Phrigya (the present research concerns a cooperation between University of Lecce and Polytechnic of Turin) a wide-range of geomatic methodologies have been experimented: GPS and traditional surveys on terrain, low-height aerial and close-range photogrammetry, high resolution satellite images processes.

The surveys have been conducted with the aim of recording metrical and non-metrical information inside a common reference system for the development of a 3D GIS of the archaeological area.

Next to archaeological evidences, many modern elements of land, such as streets, pathways and other infrastructures needed to be collected and integrated in the ancient city map. The lower accuracy and lower details requested for modern urbanization, among ground truth and close –range surveys on archaeological evidences, defined the option to process remote sensed data. Using QuickBird scene which is the highest image resolution for civil use, an orthophotomap extended to the complete ancient city area has been accomplished.

The paper also deals specially the acquisition and processing of low-height aerial imagery acquired by a camera mounted on a gas balloon UAV, to provide very large-scale maps (numeric maps and orthophoto) of a sample area, to test if such system provide good result in the ancient city environment, and to enlighten if such processed data are able to quicken and integrate other data collection systems.

The low-height aerial images has been taken by a non-metric camera at different height to produce maps at various scale. In order to realize digital or photographic maps different steps have been followed:

- Camera calibration
- Bundle adjustment solution
- Orthoprojection and/or photogrammetric plotting

To calibrate the camera some different software has been tested to obtain the internal parameters of the camera (frame camera). The bundle adjustment process has been performed using Ground Control Points and Check Points measured in the area of interest. (different sized targets have been placed on terrain)

1 INTRODUCTION

During the topographic campaign carried out between 2004-2007 a wide-range of different geomatic techniques were applied: GPS survey, total station survey, aerial and close-range photogrammetric survey. From the first GPS survey dated back 1999 realized to reference all the previous measures in a common coordinate system, every topographic operation in the area have the same reference system in order to add metrical information to the archaeological site map. Data fusion of different scale, format and semantic data are properly organized in a 3D GIS of the archaeological area and the surrounding.

In addition to the topographic and photogrammetric operations a Very High Resolution (VHR) satellite image (QuickBird) has been acquired in order to produce an orthophoto of the area. The orthophoto was employed to extract information about the archaeological evidences and the modern buildings and infrastructures present in the area.

Moreover, while the satellite images analysis has been employed by the colleagues of IBAM-CNR to discover terrain anomalies and information about scattered archeological marks, the ortho-proiection process realized has been aimed to dimension and reference to the map such archaeological hypotheses or recognized ancient constructions.

Actually, the present paper mostly detail the acquisition and the digital photogrammetric process of low-height aerial images acquired by a gas-balloon for orthophoto and numerical drawing generation.

In particular different pictures with a non-metrical film-based camera were acquired during last excavations campaigns, in order to compare typical archaeological drawings (carry out by direct survey) with photogrammetric products (orthophotos and digital drawing).

The work present the results and the product obtained with an integration of different techniques pointing out the camera calibration problems, the DTM generation by various kind of data an process (GPS survey, Total station survey and image- matching), the orthophoto production and the comparison between numerical drawing obtained after the photogrammetric process and the archaeological drawing.

2 RIGOROUS ORTHO-PROJECTION OF QUICK-BIRD IMAGES

At the moment QuickBird is the only satellite that provide the highest image resolution for civil use (Panchromatic data, ground sampling distance of 0.60 m and Multispectral data, ground sampling distance 2.40 m), therefore an orthoready image (georeferenced in UTM-WGS 84 coordinate system) chosen from the Digital Globe archive (March 2005) has been acquired and processed in order to obtain an orthophoto of the interest area (extension 25 Km2).

After the pan-sharpening process, performed by Focus PCI algorithm to carry out an high resolution colour image, a rigorous process has been performed (Toutin *et al.*, 2002):

1. Ground control points collections
2. Check Points collections
3. Digital Terrain Model generation
4. Orthophoto production (figure 1).

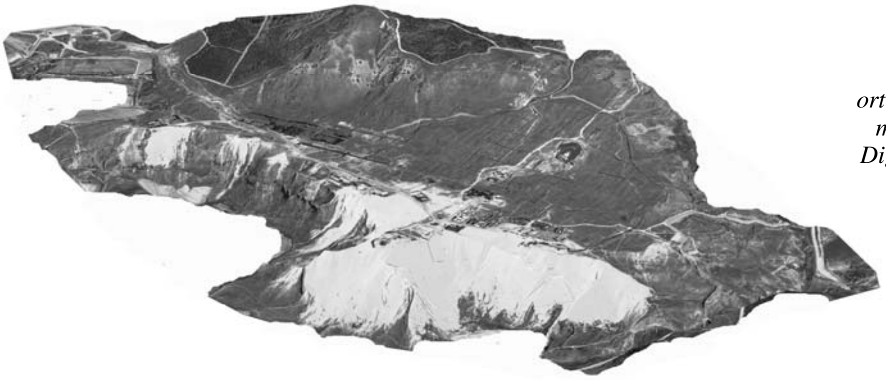


Figure 1: Satellite orthophoto and vectorial map projected on the Digital Elevation Model

3 LOW AERIAL REMOTE SENSING IMAGE ACQUISITION

For image acquisition the balloon is equipped by ad hoc platform remote-controlled; all the system is conducted from the terrain by ropes; the radio-control allow to orient the camera during the flight in order to acquire images in a correct nadir view.

The image acquisition was focused on a new excavation site close to the Martyrion of San Filippo, a flight height of about 25 m was planned in order to have an acceptable solution for an high level of detail in the product provided by digital photogrammetric processing (Althan *et al.*, 2003).

During the balloon survey a stiff breeze (typical for the area) cause an irregularity of the flight path and the radio-control was unable to impose for each image the correct nadir view, the results was a non uniform coverage of the zone with irregular overlap and convergent images.

Several images were acquired anyway and for the most important parts the area was covered from photos suitable for a photogrammetric process.

4 PHOTOGRAMMETRIC DATA PROCESSING

In order to achieve the orthophoto and the digital drawings of the analyzed areas some operations were performed: camera calibration, bundle adjustment, DTM generation, orthophoto production and digital plotting.

4.1 *Camera calibration*

First of all for a correct photogrammetric process (orientation procedures and reliable 3D metric information extraction) is necessary to calibrate the camera used during the image acquisitions. The calibration parameters concerns in the principal distance (focal length), the principal point offset and lens distortions parameters (radial and decentering distortions).

In order to obtain a correct calibration two chances are available: a calibration polygon or a 3D object acquired with convergent and rotate images in order to obtain a favourable network geometry during the calculation of the calibration parameters (we choose the second option). Moreover some well distributed points on the 3D object and in consequence on the images were measured to allow a correct computation of the parameters (Remondino & Fraser, 2006).

The images acquired by a NIKON f 90 film based camera with a 24 mm lens were scanned by a Wehrly RasterMaster RM3 (photogrammetric scanner) and calibrated in two different software (Australis and CDW-Rollei Metric), in order to compare the result of the calibration parameters.

For a correct validation of the result different sets of images has been employed, for each set (nine images) the calibration parameters has been calculate.

The following figure 2 show the result of the camera calibration:

Principal Distance	24.255 mm
Principal Point Offsets	xp = 0.140 mm
	yp = -0.076 mm
Radial Distortion	K1 = 1.299e-004
	K2 = -7.510e-008
	K3 = 6.127e-010
Decentering Distortion	P1 = -3.348e-005
	P2 = -1.933e-005

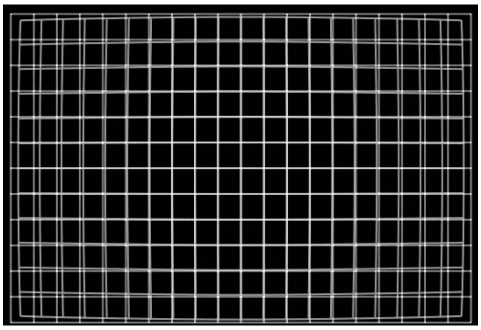


Figure 2: calibration parameters and radial Lens distortion

Several problem, first of all the film borders, were analyzed during the calibration: in a lot of case the corners are smoothed and is not easy to define correctly the edge, moreover a lot of control points must to be measured in every image; in some case, managing non-metrical cameras, is possible that the film is not leveled during the acquisition. Results show different calibration parameters for each image.

In the studied case the different calibration results were compared: differences among images were irrelevant, then a calibration certificate has been created and employed for the photogrammetric process.

4.2 *Bundle block adjustment*

The photogrammetric processing has been carried out by Leica Photogrammetric Suite, two different photogrammetric blocks were employed in order to test the methodology in different areas of the ancient city of Hierapolis.

In particular the first block was concerned with a subset of 6 images that involve the *San Filippo Bridge* zone, the second one was concerned with a subset of 4 images that covered the *Edificio Ottagonale.*

Inner orientation was performed using the image frame corners with an affine transformations, the residual were less than two pixels.

For bundle adjustment process some GCP (ground control points) are necessary to calculate the external orientation; for the analyzed areas were used first of all some target specifically realized and locate on the terrain moreover some natural points clearly visible on the images (stone corners or other particular).

All the points were measured by a GPS real time kinematic survey before image acquisition.

During the triangulation process the analytical model of the software encountered some problem due to the irregular image overlap and the imperfect nadir position of the camera during the image acquisition.

However the process achieve good result on GCP and CP (Control Points) residual, the following table show the RMS on GCP and CP after the bundle adjustment.

The results allow to obtain metrical representation with a good reliability.

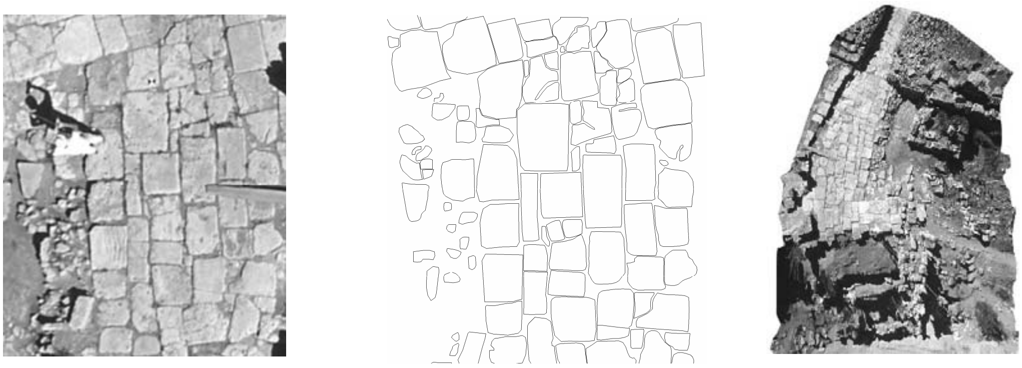
4.3 *DTM generation*

For the creation of an orthophoto at scale 1:100-1:200, is necessary to carried out a very detailed and accurate DTM, for the studied areas the previous model (generated for the satellite orthophoto) integrated by point surveyed on the terrain, break-lines and image-matching methodologies (integrated in LPS) has been used in order to create a model with about 0.50 m medium inter-post spacing. The tests shows that an integration of break-lines and points before the automatic DTM extraction process in LPS allow to obtain a better result. However an important editing was performed in order to improve the shape of the model.

4.4 *Orthophoto and digital plotting*

Orthophotos are very interesting tools for Cultural Heritage documentation, thus they combine metrical information and photographic descriptions (Karras *et al*., 1999). In the studied areas some orthophoto has been done; the low aerial orthophoto, derived from balloon images, can integrate satellite data orthomap, and provide an highest scale description. Moreover the photogrammetric plotting produce quickly a typical drawing useful for the archaeological drawings archives, accelerating diggings documentation. After image acquisition and GCP measurements, works on the areas can continue without interruption.

The following figures shows the first results on the Hierapolis areas.



Figures: 3-4-5 San Filippo Bridge: a portion of orthophoto, an extract of digital photogrammetric plotting and a view of orthophotos projected on dem.

5 CONCLUSION

The work confirm the important capability of integrated standard acquisition and methodology with photogrammetric non-conventional techniques applied to archaeological areas in order to document and represent cultural heritage and infrastructures. Today satellite and low-aerial techniques can constitute an invaluable tools for complete and rigorous low cost archaeological survey, on the other hand some aspects need to be improved: the platform stability can be refined, digital camera with best control on photogram dimensions are recommended in digital photogrammetric processes.

6 REFERENCES

Althan, O., Celikoyan, T., Kemper, G., Toz, G. 2003. Balloon-photogrammetry for cultural heritage, *Proceedings 4tInternational Symposium Remote Sensing of Urban Areas*, 27- 29 June Regensburg, Germany, 85-91.

Karras, G., Mavromati, D., Madani, M., Mavrelis, G., Lymperopoulos, E. 1999, Digital orthophotography in archaeology with low-altitude non metric images, *International Archives of Photogrammetry and Remote Sensing,* 32 (5W11): 8-11

Remondino, F., Fraser, C. 2006. Digital camera calibration methods:considerations and comparison, *proceedings ISPRS V Symposium "Image Engineering and vision metrology"*, 25-27 September Dresda Germany, 266-272.

Toutin, T., Chenier, R., Carbonneau, Y., Alcaide, N. 2002. 3D mapping with high resolution images, in: *Proceeding of 22nd EARSeL Symposium*, Prague, Czech Republic

7 ACKNOWLEDGEMENTS

The authors wish to acknowledge Prof. F. D'Andria, director of Italian Archeological Mission in Hierapolis, for joining research opportunity and Dott. R. D'Andria, author of balloon image acquisition.

Multi-scale Cultural Heritage survey: quick digital photogrammetric systems.

P. Salonia, T. Leti Messina, A. Marcolongo, A. Pozzi, S. Scolastico

CNR, Istituto per le Tecnologie Applicate ai Beni Culturali, Rome Research Area, Via Salaria, km 29.300, 00016 Monterotondo St. (Rome), Italy. E-mail: paolo.salonia@itabc.cnr.it

Keywords: 3D modelling, Multi-scale, Quick photogrammetry, Archaeology, Cultural Heritage.

ABSTRACT.

Survey technologies play a leading role in the knowledge of the cultural heritage so far they are finalized to the acquisition of data to describe geometric features and peculiarities of historical monuments for their conservation and safeguard. Moreover the demand for 3D models of historical monuments is continuously growing in the field of archaeological and architectural applications. The two main sources that can provide detailed and reliable 3D surface models are photogrammetry through image-based modelling and Terrestrial Laser Scanner through laser scanning techniques. Among the plenty of works so far presented the use of laser scanner for Cultural Heritage survey seems to aim towards a monopoly in the 3D modelling pipeline. The laser scanner technology permits a detailed three-dimensional description of the artefacts geometry, without subjective interpretation from the operators, nevertheless, up to now some geometric related issues have been not yet solved by laser scanner and thus, a great amount of post processing work is required to get final results. Recently, on the other hand, the development of digital stereo-photogrammetric systems allows the definition of 3D visualization and navigation environments; data referring to geometric consistency are combined, without loss of rigor, with other qualitative, morphological and colour information. This paper aims to present how wide could be the range of application of quick photogrammetric systems, either stereoscopic or trifocal, in surveying archaeological/architectural artefacts at different scales and for different purposes.

1 INTRODUCTION

Geometric survey represents the first step in the process of analysis and diagnosis of architectural monument state of conservation and it allows to define a geometric basis to which refer every other further information, deriving from diversified disciplinary field, so to achieve an historical-architectural integrated knowledge of the monument. Therefore geometric survey can be considered a fundamental stage for every programmed activity of cultural heritage safeguard and damage prevention. In this frame, the use of modern survey technologies allows to obtain an objective, discrete and rigorous representation of the artefact, in order to determine a global documentation (Guarnieri *et al.*, 2004), so important in the case of archaeological monuments that have complex geometry or irregular shape (Salonia *et al.*, 2006). So far the need of scientific reliable documentation, geometry and colour information, has led our research group either to choose a multimodal approach for the survey activities, either to query and test quick digital photogrammetry systems to accomplish the task. A research project has been carried out by CNR Institute for Technology Applied to Cultural Heritage (CNR-ITABC) and the Superintendence for Cultural and Environmental Heritage of the Valle d'Aosta. The Valle d'Aosta Autonomous Region (RAVA) is determined to direct one's intervention policy, for cultural heritage conservation, towards preventive programmed maintenance, based on the constant monitoring of risk situations and the management of systematic conservation interventions.

2 THE STUDY CASES

The first artefact investigated in the present study consists of the entire ancient Roman city wall of Aosta (figure 1), still today almost entirely conserved. The stereo photogrammetric coverage of this monument, that has a total length of over five kilometres between the external and the internal side, became necessary for the purpose of preparing a scientific basis of geometric data, finalized to evaluate the state of conservation and to plan the subsequent conservative restoration actions.

The second artefact is the imposing roman triumphal arch of Augustus (figure 2), build in the 25 B.C. as a tribute to the emperor Augustus and also for celebrating the military victory of the roman troop over the Salassi tribe that occupied the Valle D'Aosta since the II century B.C (Corni, 1989). The arch, build with pudding ashlars and characterized by a mixture of Doric and Corinthian order, is situated in the east edge of Aosta and it is aligned with the axis between the external roman bridge and the walled town east access, the Porta Praetoria.

The third is the medieval cloister of S. Orso (1133) (figure 13), with its outstanding 37 marble engraved capitals. The capitals present a complex geometry, characterized by decorative figures in high-relief that represent several scenes belonging to the Old Testament or to episodes of the S. Orso life.

The fourth is the II sec. A.D. roman *Balteus* of Aosta (figure 3), an ancient bronze horse pectoral, for parade or perhaps for award (Carducci, 1960), with figure tracery representing a fight between Romans and Barbarians, recognizable from the typical clothing. The fight scene, developed on a semicircular bronze belt , is based on Hellenistic schemas, going back to models from Traianus time: the composition consists of figures separated from the background, with deep shadows, and reveals the typical Aurelian taste for relief technique.

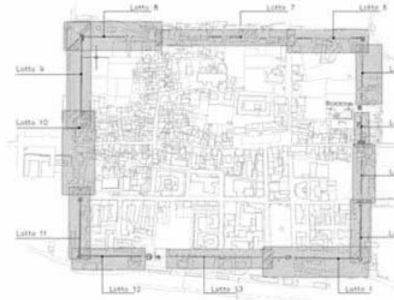


Figure 1.

Figure 2.

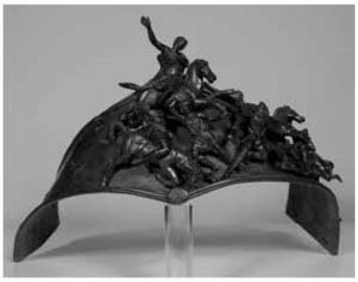


Figure 3.

3 METHODOLOGY AND TECHNIQUES USED

Concerning the stereo photogrammetric survey, the adopted system is either the Cyclop II (figure 4), for the wall (figure 5) and the arch (figure 6), or the innovative instrumental system ZScan (figure 7), for the Balteus and the cloister*. Moreover after detailed preliminary inspections, data acquisition of the arch of Augusto have been planned as to perform both the stereoscopic coverage and the laser scanner acquisition so to compare results and methodologies. Concerning the 3D laser scanner survey, a Leica HDS2500 laser scanner (former Cyrax 2500) has been used. The need to compare these different survey technologies becomes fundamental to verify the accuracy of acquired numeric data, to evaluate their possible integration and to define different protocols of use in relation to the artefacts morphological-architectural characteristics and to survey finalities. On the same 3D model has been reported the exact position of several sensor arranged on the monument in order to estimate the variation of climatic conditions on the artefact surfaces and all other relevant data related to the monument state of conservation. The 3D reconstruction has been useful also to analyze the complex relationship between materials and different alteration phenomenology as well as decay pathologies variability in relation to the influence of the environmental context (Salonia *et al.*, 2007).

Cyclop II is a quick non-conventional stereo-photogrammetric system that guarantees reliability from the point of view of measurement rigor, as well as satisfying characteristics of considerable flexibility and ease of use (Menci, 2000). This innovative photogrammetric system is a digital mono-camera system which has the advantages of a bi-camera and allows stereoscopic acquisition that can be used directly for restitution. This system guarantees the same accuracy of geometric data acquisition as a traditional stereoscopic method, which is fundamental in the process of diagnosing the state of conservation.

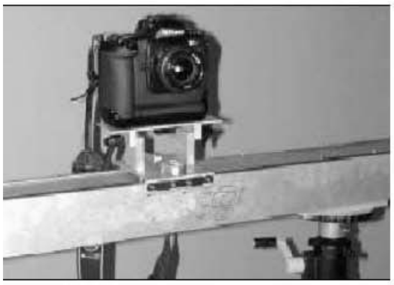


Figure 4.

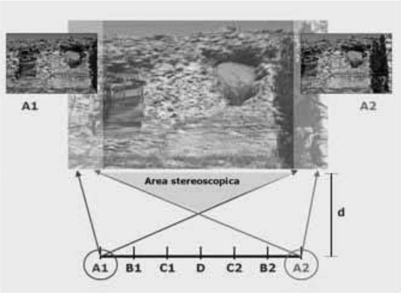


Figure 5.

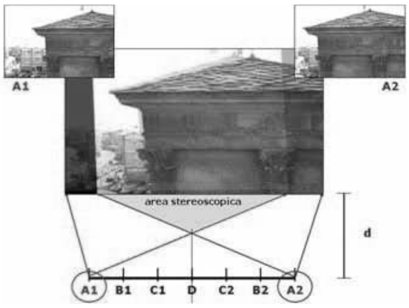


Figure 6.

---

[*] Cyclop II and ZScan survey systems are both manufactured by Menci Software of Arezzo.

Although the system doesn’t need topographical support, the latter was nevertheless provided in order either to verify the reliability and the accuracy of the obtained results, to properly set the stereoscopic models in real space or to link different stereoscopic models and geo-reference the final strips.

ZScan is a low cost close range sensor, that allows the digital scanning of multi-view high quality images sequences (figure 8), through the application of a sophisticated algorithm for image processing based on stereo-photogrammetric principles. This new technology can be used to obtain RGB points clouds (figure 9) and geometries at different levels of complexity, starting from the treatment of a number of images, taken with a limited set of constraints and with the use of calibrated digital camera and a special acquisition equipment.

It consists on a digital calibrated photographic camera applied to a sleigh bound that flows on a rectilinear special steel guide mounted on an aluminium bar which is positioned on a common topographical tripod.

Considering the use of a single photo camera, both the systems have many advantages, as cheapness, accuracy (a single calibration), constructive homogeneity (same response to colour and same defects in general).

Moreover, they do not require topographical support in order to obtain single stereoscopic or 3D models.

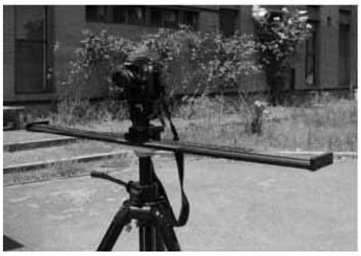


Figure 7.

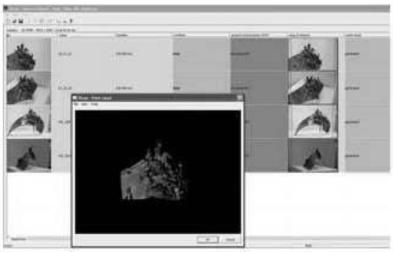


Figure 8.

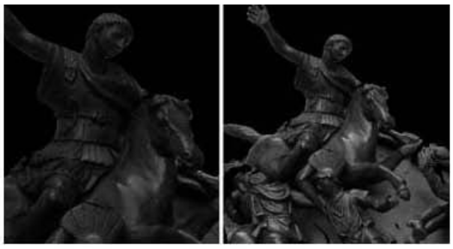


Figure 9.

4 DATA PROCESSING AND TREATMENT

The photogrammetry elaboration phase consisted in loading the single digital images acquired, into an ad hoc software, Cyclop II of Menci Software, which allows to create immediately the single stereoscopic couples so to obtain three-dimensional management (control, measurement, etc.). All the photographic stereoscopic pairs have been processed with added control points (natural and targets deriving from topographic survey) in order to minimize errors in overlapping models (figure 11). Raster strips own such a notable quantity and variety of information, which derive from the geometrically controlled stereoscopic pairs (figure 10), that the vector phase, which often represents a subjective abstraction from the truth, can be considered superfluous.

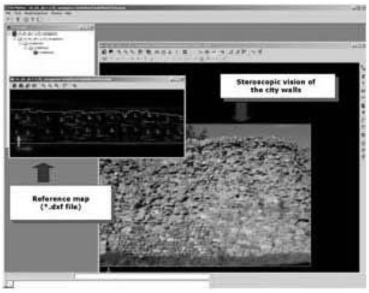

Stereoscopic vision of the city walls
Reference map (*.dxf file)

Figure 10.

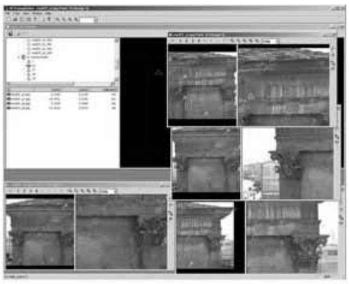


Figure 11.

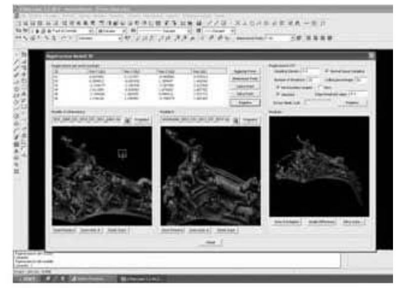


Figure 12.

For what concern the S.Orso cloister and the *Balteus* dataset, every single triple sequences of images (figure 8), have been processed through a dedicated software that is part of the ZScan instrumental survey system for extracting from each of them a specific RGB points clouds. This software allows to rapidly load, without any preparatory phase, the three images of each scan position and the relevant acquisition parameters: the baseline adopted and the calibration file of the lens used. The points cloud contains both spatial and colour information, xyz co-ordinates and RGB values for colour rendering; moreover, in order to display a texture representation, it is also possible to create a mesh of every single points cloud (figure 14) and then to merge them together (figure 12) in order to reconstruct the artefact itself.

Evidence is to put on the cloister (figure 13) survey, where the quick digital photogrammetric system fulfil the task of a multi scale documentation; laser scanner technology would have meant to utilize both time of flight and optic triangulation sensor for closer detail with the obvious increasing surveying costs. Digital photogrammetry offers at the same time a quick and high quality data capture, within millimetric accuracy for 3D reconstruction and inspection of archaeological artefacts. Still work in progress, the capitals survey aims to research low cost range sensors compared to laser scanner technology, to develop a new methodology based on digital surveying techniques, moreover to enlighten and solve many of the critical aspects owed to the images capture as for example: planning shots so to cover all the undercuts of figures; light, shadows and colour control; color balance and equalization between different shots; different focusing for coupled pillars; clouds registration as the system has been thought for quasi-planar surfaces and linear geometrical development. The 3D digital model of the capitals obtained (figure 15), completely fulfil the Public Administration demand of accurate measurements useful for their eventual reconstruction in case of physical and structural damage and offers a database built on information layers of deeper structural and iconographical complexity and detail.

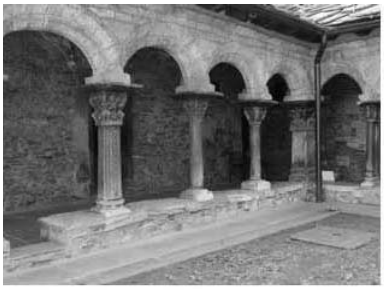


Figure 13.

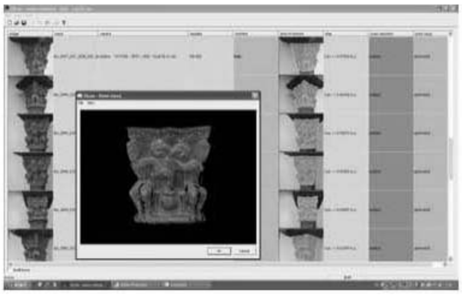


Figure 14.

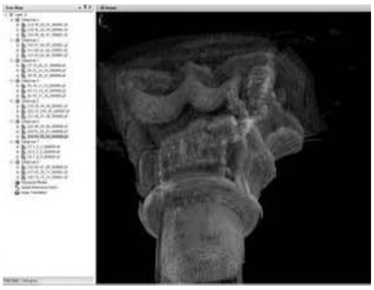


Figure 15.

5 CONCLUSIONS

The work as far as here presented remarks how "traditional" ways can still be pursued and enforced as valid applications to survey Cultural Heritage. Systems based on image capture and processing, for digitization and 3D model reconstruction can be widely applied to different scale archaeological artefacts, also allowing common users to quickly understand their configuration and peculiar characteristics (Martinelli, 2006).

Digital photogrammetry has given satisfactory results in terms of surveyed number of points and precision in the location of the acquired surfaces, taking advantage of scanner laser technology, the use of which being more affected by the scale of the artefact in terms of LOD cannot be applied for a multi scale project survey without shifting from a time of flight sensor to the optical one. Moreover digital quick photogrammetry achieving at the same time both the geometric and the colour documentation (points clouds with RGB colour information), photo-realistic 3D models could be easily outputted on as a high quality level as of those created from laser scanner's dataset trough a longer post-processing texturing work.

Morphological details or components materials and colorimetric definitions so could be extensively exploited in further analysis by specialists from various technical fields.

Finally is to underline the low cost of this technology which offers to peripheral museums or small Public Administration the opportunity to plan surveys and preservation of own artefacts otherwise not possible if more expensive technologies and methodologies, as laser scanner sensors, are involved, that question us on ethical responsibilities of the use of too expensive hardware in Cultural Heritage knowledge.

6 REFERENCES

Carducci, C. 1960. Ancora sul balteo di Aosta. *Boll. Stor. Bibliogr. Subalpino*, LVIII, fasc. I-II, January-June, p. 55 and fol.

Corni, F. *1989. Aosta antica. La città romana*, Aosta.

Guarnieri, A., Remondino, F., Vettore, A. 2004. Photogrammetry and ground-based laser scanning: assessment of metric accuracy of the 3D model of Pozzoveggiani church. In *Proceedings of the FIG Working week 2004, "The Olympic Spirit in Surveying"*, Athens.

Martinelli, M. 2006. Passato e futuro del 3D archeologico, dalle foto stereoscopiche al computer per l'architettura antica. *Arkos*,16 : 18-23.

Menci, L. 2000. StereoSpace: an idea for photogrammetric data collection. In *Proceedings of XIX ISPRS Congress*, Amsterdam.

Salonia, P., Scolastico, S., Bellucci, V. 2006. Laser scanner, quick stereo-photogrammetric system, 3D modelling: new tools for the analysis and the documentation of cultural archaeological heritage. In *Proceedings of the 2nd International Conference on remote sensing in archaeology*, Rome.

Salonia, P., Bellucci, V., Scolastico, S., Marcolongo, M., Leti Messina, T. 2007. 3D survey technologies for reconstruction, analysis and diagnosis in the conservation process of cultural heritage. In *Proceedings of Cipa 2007 – XXI International Symposium. Anticipating the future of the cultural past*, Athens.

Contribution of Satellite imagery and DEMs to the Detection of Neolithic Settlements in Thessaly, Greece

D. Alexakis[1], A. Sarris[2], Th. Astaras[1] , K. Albanakis[1], D. Oikonomidis
[1]Remote Sensing and GIS Applications Laboratory Department of Physical and Environmental Geography, School of Geology, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece, alexakis@chania.teicrete.gr,astaras@geo.auth.gr

[2]Laboratory of Geophysical – Satellite Remote Sensing & Archaeo-environment, Institute for Mediterranean Studies, Foundation for Research & Technology, Hellas (F.O.R.T.H.), Rethymno 74100, Crete, Greece, asaris@ret.forthnet.gr

Keywords : Remote Sensing, DEM, Thessaly, Neolithic.

ABSTRACT.

Thessaly is a region of low relief in Greece where hundreds of Neolithic settlements/tells called magoules were established from Early Neolithic period until Bronze Age. Multi sensor remote sensing was applied to the study area in order to evaluate its potential to detect Neolithic settlements.

Moreover, different kinds of digital elevation models were used such as SRTM, DEM constructed by interpolation of contours from topographic maps, DEM constructed by aerial photos and DEM constructed by Aster images, where tells can be identified as small contrasting spots within the elevation pattern of the natural variation of the land surface.

A range of image processing techniques such as colour composite, principal components analysis, de-correlation stretch, followed by visual interpretation, were originally applied to the hyperspectral imagery in order to detect the settlements and validate the results of GPS surveying. The next step was to collect spectral signatures of these tell sites, to correlate them within the same spectral range of the different sensor systems and finally to proceed with their statistic analysis. Various filters were applied to all images to explore the high spectral and spatial variability of the settlement patterns, such as Sobel 3*3 right diagonal and Laplace filter. Classification of all the images using different hard and soft classifiers and application of vegetation index NDVI was followed. To cope with the difficulties of pixel based methods, object–oriented classification techniques were also applied to Ikonos imagery to classify tells according to their shape and geometry.

In addition, sophisticated filters were applied to each DEM in order to detect the settlements. After validating the results with real altitude data, we concluded which of them are more reliable either for general topographic studies of the area or more specifically for the detection of the settlements. The final step was the application of fuzzy algorithms for the classification of the possibility of settlement existence.

Although there are specific difficulties encountered in the classification of archaeological features composed by a similar parent material with the surrounding landscape, the results of the research suggested a different response of each sensor to the detection of the Neolithic settlements, according to its spectral and spatial resolution. Moreover, the integrated use of remote sensing imagery and the digital elevation models produced an important enhancement to the design of a predictive model of the Neolithic settlements of Thessaly by combining the spectral, spatial and topographic attributes of the tells.

1 INTRODUCTION

The spectral capability of early satellite sensors opened new perspectives in the field of archaeological research. The recent availability of hyperspectral and multispectral satellite imageries has established a valid and low cost alternative to aerial imagery in the field of archaeological remote sensing. The high spatial resolution and spectral capability can make the VHR satellite images a valuable data source for archaeological investigations ranging from synoptic view to small details (Masini and Lasaponara, 2007). In this study the satellite data have been statistically analysed together with other environmental parameters to examine any kind of correlation between environmental, archaeological and satellite data.

2 RESEARCH METHODS AND MATERIALS

The study involved satellite image detection of Neolithic Settlements in Thessaly by incorporating the following satellite and digital spatial data: 4 ASTER images, 1 LANDSAT ETM image, 1 HYPERION image, 4 IKONOS images, 5 airphotos, GPS surveying measurements of more than 342 Neolithic settlements of Thessaly and a digitized DEM of 20 m pixel size of the study area.

3 SATELLITE IMAGE PROCESSING

The image processing of satellite data was carried out in two steps. Initially, we started with the preprocessing procedures and then we continued with the main image processing steps.

3.1 *Preprocessing of Satellite images*

Before starting the image processing we masked the sea, the clouds and the snow areas of all the images. Then we proceeded to the construction of image mosaics and transformation of the projection systems to a common projection system (EGSA87/HGSR87). In the end, the DN values of the images were converted to reflectance values.

3.2 *Composition of RGB composites*

Several RGB composites were constructed in an effort to examine their efficiency in the detection of the Neolithic settlements. For the ASTER image with acquisition date 19-03-2003, where most of the magoulas are registered, the RGB→1,2,3, RGB→3,2,5 and RGB→2,3,7 composites have been the most successful for the detection of the Neolithic settlements (39 out of 239 settlements were highly visible, 49 average visible and 151 poorly visible). Similarly, RGB composites of IKONOS images were able to detect 27 in a total of 48 settlements. It is worth mentioning that 19 of the detectable magoulas, namely the highest of all corresponding to an average altitude of 4.6m, were highly visible in all RGB composites. On the other hand, RGB composites of Landsat and HYPERION images were not very promising (for HYPERION composites only 5 settlements were detected in a total of 21). Finally, average altitude aerial images contributed to an excellent detection of all the 5 settlements that were inside the spatial limits of the airphoto mosaic. As a general conclusion however, the most crucial factors for the detection of magoules proved to be the acquisition date of the image due to the fact that the terrain of the majority of the settlements is cultivated (mainly soft/shallow cultivation).

3.3 *Spectral Profile Comparison and Classification*

The identification of spectral signatures was considered to be a crucial task for the detection of Neolithic settlements especially for the classification process. Signatures were collected from all the tells and were divided in to two categories: Those collected from plain areas and those collected from mountainous areas due to different soil cover.

3.4 *Principal Component Analysis*

We applied PCA to ASTER, Landsat and Hyperion Images. PCA of ASTER images provided the best results where 39 settlements were highly discriminated and 47 medium discriminated in a total of 247.

3.5 *Image Fusion*

Image fusion is a standard satellite image procedure of combining images of different spatial resolution to obtain a single final composite image. Various fusion combinations were tried, such as ASTER (15 m) visible channels with the PCA product of HYPERION (30m) or the high resolution (1m) bands of IKONOS with the PCA product of HYPERION. The results were highly promising for the cases of fusion between high spatial resolution and high spectral resolution images.

3.6 *Spectral Mixer Utility*

In order to exploit the high spectral resolution of HYPERION images, we applied a spectral mixer utility of Erdas Imagine 9.1. Spectral Mixer produces three bands to be assigned to the red, green, and blue color guns, but in this case instead of just assigning each band to a color gun we could select a weighted average of spectral bands to be assigned to a color gun (Erdas Field Guide, 2006). For HYPERION images only the bands that have reflectance values above 0.3 were used and we assigned a weighting coefficient of 0.14 for each band. The new RGB that was created (RGB1) employed the mixing of the bands (38, 42, 48, 49, 50, 51, 52), (85, 86, 87, 88, 89, 90, 91, 92,) & (93, 94, 108, 109, 110, 111, 113, 114).

3.7 *Radiometric Enhancement*

Radiometric enhancement was vital for the appearance of the images. After applying radiometric enhancement to ASTER images (acquisition date of 19-03-2003) we managed to detect 57 settlements. A non-linear radiometric enhancement of the HYPERION PCA image, followed by an inversion of brightness was able to highlight 8 settlements from a total of 9. Similar type of non-linear radiometric enhancement of the high resolution Ikonos images through the modification of the histogram was able to outline the round shape of known magoules, as well as to identify 10 more targets of similar geometry that need to be verified by the ground truthing activities that will follow (Fig 1).

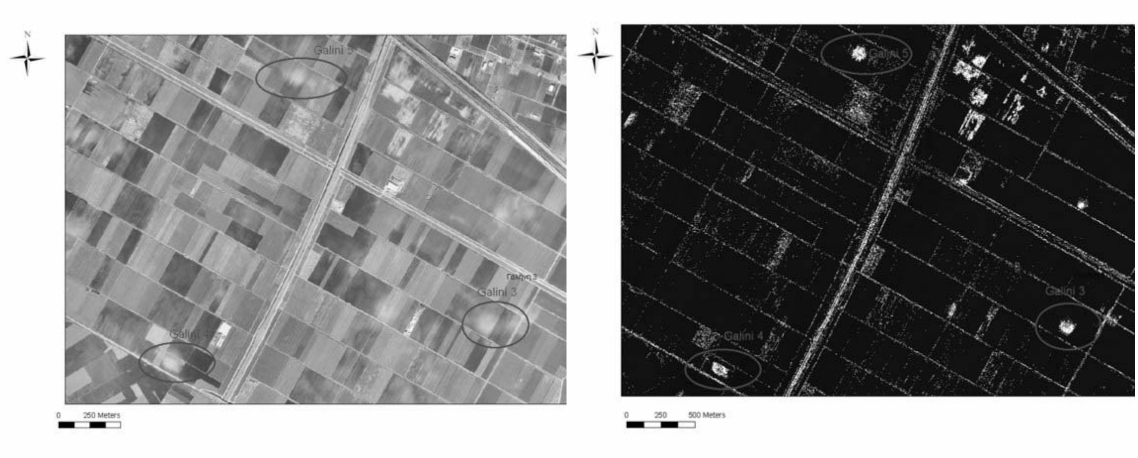


Fig. 1. Appearance of 3 settlements in the original IKONOS image (left) and the radiometrically enhanced image where three Neolithic settlements are highlighted (right). To the north of Galini-3 settlement, shown at the lower right of the image), another smaller potential magoula is suggested.

3.8 *Land Classification and Vegetation Indices*

In the domain of predictive modeling, the specification of the environmental attributes that correlate to the location of the archaeological sites is of importance. For this reason, in order to investigate the regime of the land use surrounding the magoules, several methods of supervised classification were applied to Landsat and ASTER images. Mahalanobis classification proved to be the most efficient one in terms of the overall accuracy assessment compared to all the classification algorithms that were applied (8 in total). The Normalised Difference Vegetation Index (NDVI) was computed to analyse the difference of vegetation during various acquisition dates. As expected, the NDVI of the spring ASTER image was higher than the summer Landsat image.

3.9 *De-correlation Stretch*

The de-correlation stretch is a process that is used to enhance (stretch) the color differences found in the input pixels. After we applied de-correlation stretch to the ASTER images, we managed not only to detect easily 36 Neolithic settlements, but also to obtain estimates of their extent.

3.10 *Spatial Enhancement*

Spatial enhancement of images is considered to be a standard satellite image enhancement. Of the several types of filters that were applied in the specific study, only two of them, Sobel Right Diagonal 3x3 and Laplace 3x3, proved to be very useful for the detection of Neolithic settlements (Fig 2).

3.11 *Predictive Modeling*

The results of land use classification, NDVI estimates and those from the spectral signatures and classification of the ASTER image (acquisition date 19-03-2003) were combined together with a DEM constructed by digitization of 1:50.000 scale topographic maps. All data were reclassified and a certain weight factor was applied to each of the raster layers. After constructing the final map we estimated that 92 of the known settlements are laid on areas of high probability and 23 in areas of medium probability.

4 APPLICATION OF SOPHISTICATED FILTERS TO DEM.

The study involved detection of Neolithic Settlements through the use of Digital Elevation Models (DEM). For this purpose we used three different kinds of DEM: SRTM DEM of 90 m pixel size, ASTER DEM of 30 m pixel size and the DEM from digitized contours of 20 m pixel size.

For the detection of the Neolithic settlements we used three different methodologies to the above DEMs. The first methodology involved the estimation of the index of convexity according to Fry et al (2004). The second methodology had to do with the creation and application of customized filters similar to those used by Menze et al (2006). The third methodology followed the approach of Iwahashi and Kamiya (1995) for the estimation of geometric signatures of DEM which involved the integrated study of slope gradient, surface convexity and texture of the study area. To the final results of the filtered DEM, algorithms of fuzzy logic were applied in order to obtain better classification results.

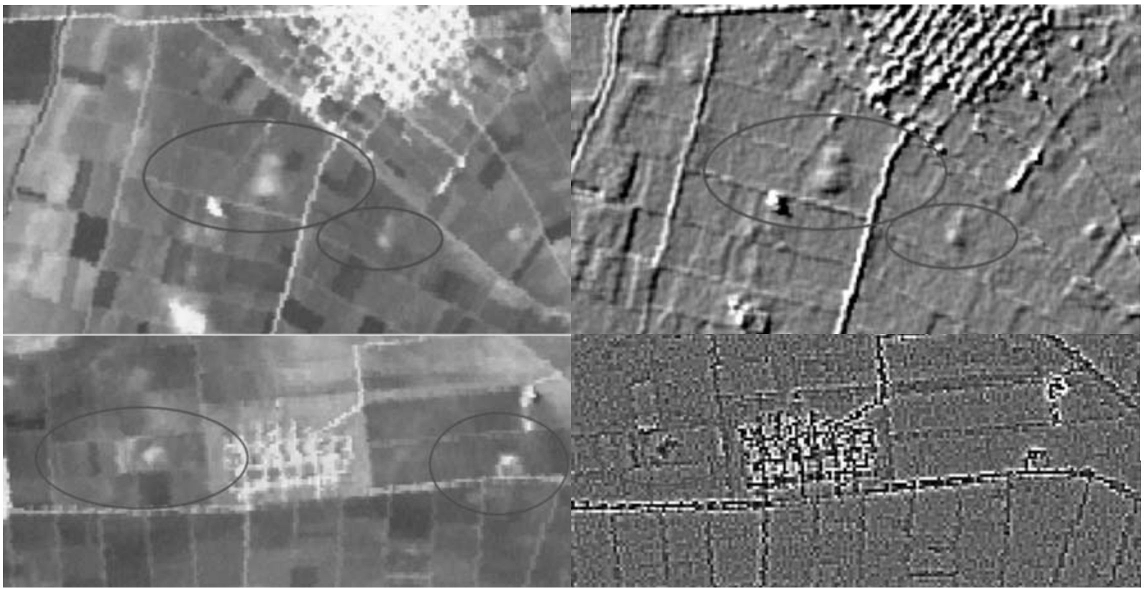


Fig 2. Original ASTER image (RGB→ 1,2,3) around Halki area (Top Left) and the corresponding image after the application of Sobel Right Diagonal filter (Top Right). Original ASTER image (RGB→ 1,2,3) around the settlements of Elliniko 1 and Elliniko 2 (Bottom Left) and the corresponding image after the application of Laplace Filter (Bottom Right)

5 CONCLUSIONS

ASTER images proved to be the most reliable and efficient for the detection of Neolithic settlements. In contrast, Landsat images did not produced satisfactory results, mainly due to the summer acquisition date of it. The high spectral abilities of HYPERION, especially after merging it with the high resolution images of Ikonos, seem to have an increased potential not only for detecting but also for outlining the particular features. The image processes that proved to be more effective were the spatial filtering, the process of de-correlation stretch and the radiometric enhancement. In addition the results of the analysis of DEMs, especially the application of the three different filters to SRTM DEM, proved to be very promising.

6 REFERENCES

Erdas Field Guide 2006. Erdas Inc, Atlanta, Georgia

Fry, G.L.A., Skar, B., Jerpansen G., Bakkestuen V., Erikstad L. 2004. Locating archaeological sites in the landscape : a hierarchical approach based on landscape indicators, *Landscape and Urban Planning* 67: 97 – 107.

Iwahashi, J., Kamiya, I., 1995. Landform classification using digital elevation model by the skills of image procesing—mainly using the Digital National Land Information. *Geoinformatics* 6 (2) :97–108 (in Japanese with English abstract

Masini, N, Lasaponara, R. 2007. Investigating the spectral capability of Quickbird data to detect archaeological remains buried under vegetated and not vegetated areas, *Journal of Cultural Heritage* 8: 53-60.

Menze, B.H., Sherratt, A.G. 2006. Detection of Ancient Settlement Mounds: Archaeological Survey Based on the SRTM Terrain Model, *Photogrammetric Engineering & Remote Sensing*, 72: 321 – 327

Kite Aerial Photography (KAP) as a tool for completing GIS models. Ptolemais (Libya) case study.

M. Bogacki, W. Małkowski, K. Misiewicz

Institute of Archaeology , University of Warsaw, Warsaw 00-927, Poland, wmalkowski@uw.edu.pl

Keywords: non-destructive archaeology, GIS, aerial photography, kite photography, orthophotomap

ABSTRACT

The Kite Aerial Photography (KAP) is a technique that allows to take aerial photos from variable heights between few meters to hundreds meters, raising the camera by means of a kite. There are two instruments necessary in order to make aerial photos: a kite that allows to raise a camera and a photographic system(simple or equipped with radio). The camera is mounted on a structure called cradle or rig. Several types of flow forms: self-inflated, airfoil-shaped kites that have no rigid components were used on the site. The rig is made of aluminum plates with steel rods and aluminum gears for rotation axes. The total flying weight (without camera) was ca. 1,3 kg. The rig allowed to attach the camera to the kite line and to aim the camera in any direction. We are able to pan, tilt and rotate cameras from the ground using an RC transmitter. We also used time-lapse controllers for digital cameras to operate the camera from a distance, take pictures, adjust the lens zoom etc.

The system described above has been used by the Polish Archaeological Mission of the Warsaw University to Ptolemais in Libya (Cyrenaica) since 2006. After two work seasons about 6000 photography (vertical and oblique) were taken. Some of them were georeferenced and adjusted with satellite images and topographical plans, prepared as a result of topographical survey carried out on this site since 2002. Photographs were processed (georeferenced and adjusted) with the use of Autocad Map 3D software with additional special modules for calibration (for example RASTER DESIGN) and preparation of Geotiff images. High resolution photographs were obtained with the use of KAP – 0.1 m per pixel, while the best available analyzed satellite images have a resolution of c.a. 0,5 m per pixel. Orthophotomaps in the form of mosaics of georeferenced images were obtained in result of calibration and transformation processes. Accuracy of transformation was checked by the calculating of the Total RMS (Root Mean Square) Error (Woolf & Dewitt, 2000). Preparing the 3D surfaces on the base of orthophotomaps connected to DTM (Digital Terrain Model – built on a base of topographical GPS and Total Station measurements) was the new approach for processing KAP. All processed data, such as: KAP orthophotomaps, satellite ortho-images, topographical plans, DTM models and georeferenced geophysical images can be presented as independent layers of a digital model made in AUTOCAD GIS module. By adding databases to this model we are able to transform all data to GIS system and use it as a powerful tool for reconstructing ancient town planning. All activities described above were necessary in the case of Ptolemais where the surface of the site to be surveyed is over 200 hectares.

1. EQUIPMENT AND TECHNICAL ASPECTS.

Using a kite for archaeological documentation seems to be the best solution for preparing photomaps according to survey plan made with Total Station. Remote sensing camera gives us a possibility for choosing the best frame for each building as well as adjusting the best angle for extrude the necessary details

At the moment suitable set for taking aerial photos using photo-kite contains: digital camera Olympus E510 with live view option, Zuiko lens 14-54 mm 2.8, radio transmission set 2,4 gHz, aluminum rig with servo for camera positioning, photo kite flow form type (different sizes according to wind strength).

It is very important to use special camera type with stabilization system and possibility of on-"live view" transmitted to ground signal receiver. System of positioning camera exactly in wanted place are available using servos system with picavet lines. This system gives us a possibility of perpendicular or oblique kind of documentation. All necessary activities (rotations, shutter control) are remote controlled by radio-aparature and the effect is visible on the small, integrated monitor LCD.

Calibration and transformation process in case of raster images which ware made using photo-kite system for aerial photography from average height.

Aerial Photography in case of archaeological site from average or large height demands later elimination of defects of the optical arrangement – distortion effect, which makes local differences in some parts of photography. Moreover distortions of photos are caused mistake of parallax, shifts of got image in relation to observed. At last accidental swings of camera or at last inequalities of terrain also makes a defects. Most from these faults were been possible to improve by calibrating photo digital system to processing of bitmapped images. Choosing suitable method of transformation gives us possibility of reduction of most mistakes exists into result of photographing or scanning. Calibration is process of adjusting in case of digital images for suitable geometry across indication of concrete points on images and then defining of theirs equivalents in expecting geometrical arrangement.

Differences of distance among adapted photo-points (markers), and points of geometry give us result of average mistake of calibration. Following attributing information such as scale, rotation, coordinate system were simultaneously being added by the process of calibration. In effect of this process we can get georeferences – that is information about co-ordinate corners, scale, rotation of transformed photo.

2. CAMERA RIG AND PICAVET SUSPENSION

The camera is attached not directly to the kite but is secured to an adjustable rig suspended from the kite line at a distance 10 – 15 m from the kite. This distance reduces excessive movement being transmitted from the kite to the camera.

A Picavet suspension, consists of a rigid cross suspended below the kite line from two points. A single line is threaded several times between the points of the cross and the points of attachment to the kite line and the rig is attached to the cross (figure 1a)The line runs through small pulleys and the weight of the rig causes it to settle naturally into a level position.

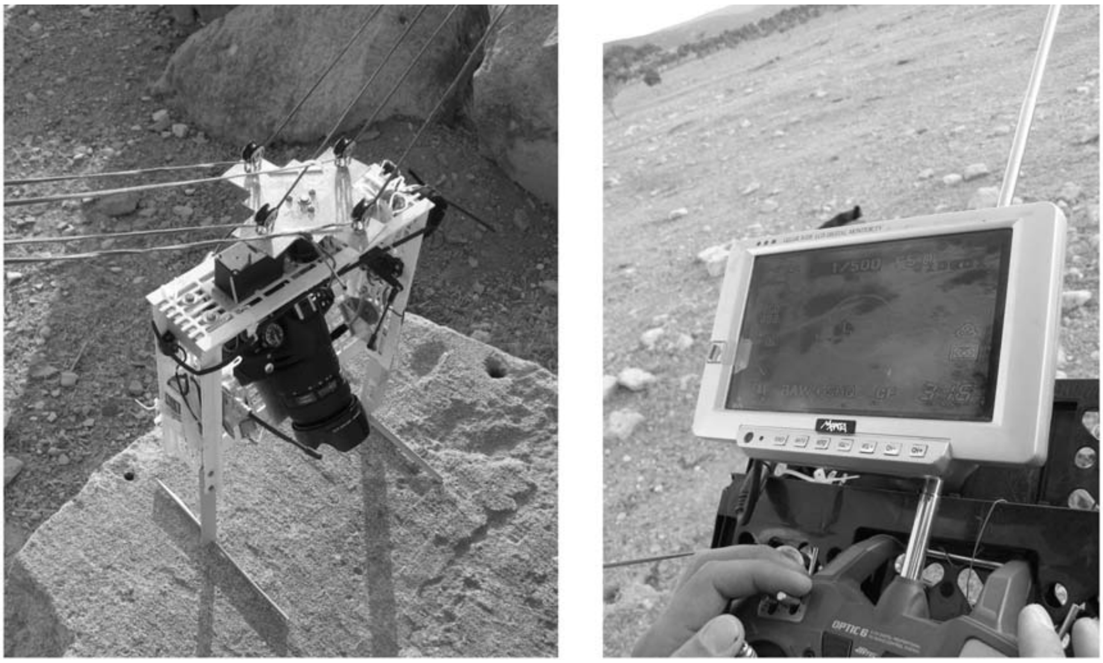


Figure. 1 Camera rig with picavet suspension (left) remote sensing control aparature with LCD monitor (right)

3. REMOTE SENSING CONTROL

The camera is fitted within a frame and can be designed to rotate horizontally and vertically Adjustments to these angles can be made by the use of a radio remote control system (the same as used for model aircraft). The servos in these systems are adapted to adjust rig positioning. Shutter release mechanisms including a radio controlled servo and an infrared signal is used to instruct the camera to release the shutter. Automatic controllers have been developed that can take a photo, move the camera by a set angle and finally to transmit the picture from camera to LCD monitor (figure 1b).

4. IMAGE PROCESSING

An aerial photograph has been planimetrically corrected to remove distortion caused by camera optics, camera tilt, and differences in elevation. The next step is a scanning of phothos into a raster image file format. The image is rectified and georeferenced using mathematical models of photogrammetry for the removal of tilt, terrain, and other digital image distortions. Aerial photographs are produced into digital orthophotos by dividing the given area of a photograph into very small, equal sized pixels. The geometric correction of aerial photographs requires the calculating of distortion at each point, and then shifting the image to the proper location.

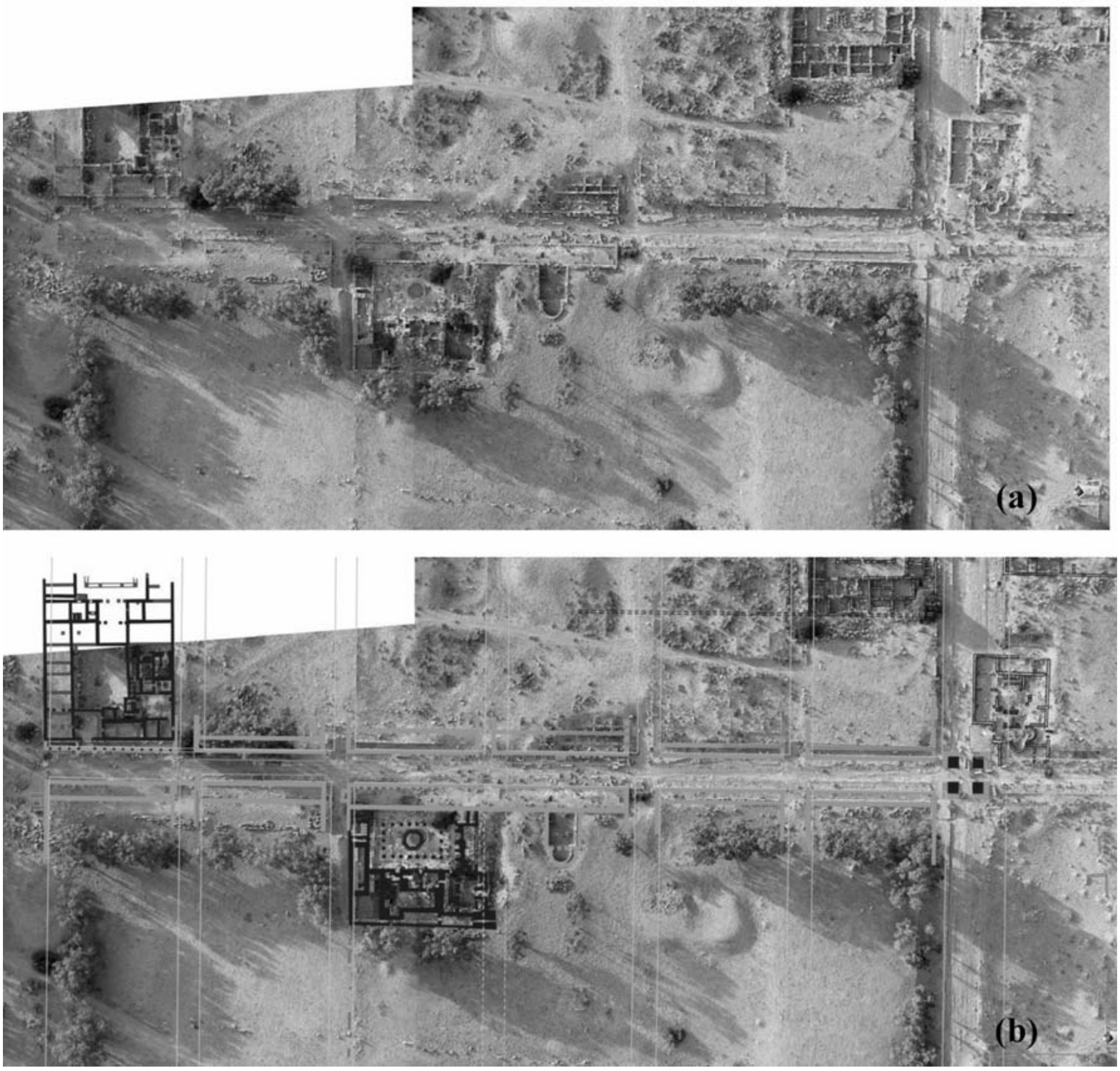


Figure. 2a-b.

A digital terrain model can be added as a means of collecting ground points to indicate the changes in elevation. When control points are identified on the aerial photos, stereomodels can be developed. All this operations were made with a computer program (AUTODESK RASTER DESIGN GEOX KALIBRONEK CODER MIKROMAP) which takes into consideration the camera location, the orientation of the camera, and the heights of all points in the grid of the area photographed. The displacement is calculated for each point in the raster image, and distortion is removed for each raster cell. (figure 2a).

The next step is a combining of ground-surveyed measurements with measurements taken on aerial images to provide precise, orthographically correct coordinate locations. All measurements of the photo are combined with real x, y, and z coordinates in the field and all features measured on the ground (figure 2b). Maps illustrating the result of geophysical surveys can be used as a layer of prepared maps (figure 3).

An aerial photograph has been planimetrically corrected to remove distortion caused by camera optics, camera tilt, and differences in elevation.

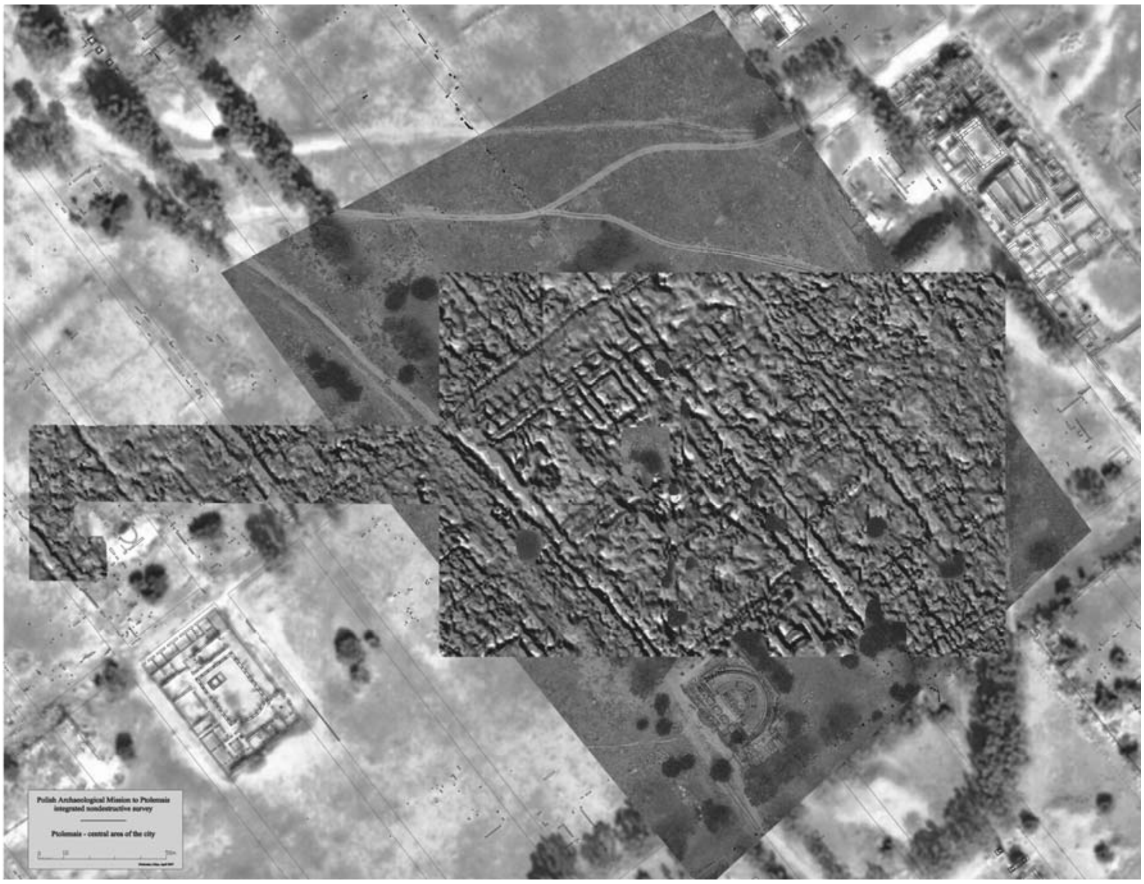

Polish Archaeological Mission to Ptolemais
integrated nondestructive survey
Ptolemais - central area of the city
0
10
50m

Figure 3 Topographical plan , satellite and kite images merged with geophysical survey map.

5. REFERENCES

Wolf, P.R., Dewitt, B.A. 2000. Elements of photogrammetry with applications in GIS. McGraw Hill, Boston

Development and use of a 4D GIS to support the conservation of the Calakmul site (Mexico, World Heritage Programme)

M. van Ruymbeke[1], V. Tigny [2], E. De Badts [2], R. Garcia-Moreno [1] & R. Billen [1, 3]

1 *University of Liège, European Centre of Archaeometry, Allée du 6-Août 17, B 4000 Liège, Belgium, (mvanruymbeke, RG.moreno)@ulg.ac.be*

2 *GIM , Heverlee, Belgium, (vincent, erik)@gim.be*

3 *University of Liège, Geomatic Unit, Liège, Belgium, (rbillen)@ulg.ac.be*

Keywords: GIS, Remote Sensing, ICT, World Heritage, Archaeology

ABSTRACT.

The present project proposes to develop and implement an "Information Management System" for the conservation authorities of the Biosphere Reserve and Archaeological Urban Centre of Calakmul. This online system will allow Mexican managers of Natural and Cultural Heritage, and scientists to store, share and create interaction between their data, in order to coordinate various actions of conservation, management, planning, monitoring and research undertaken in the area. It will benefit from new developments in the GeoICT, Archaeomatic and Spatio-temporal Analysis, Computer Vision and Earth Observation fields and will integrate 2D GIS layers, 3D objects and time. An innovative scientific protocol is proposed to incorporate complex archaeological data in a GIS.

1 INTRODUCTION.

1.1 *Aims.*

In the present project, the name "Calakmul" refers to an ecological reserve including an ancient Maya city. The study zone lies in the South East of the Campeche State, in the middle of the Yucatan peninsula (Mexico).

The Calakmul Biosphere Reserve was created in 1989. It covers an area of almost 7.300 square kilometers and constitutes one of the largest protected forests of the tropical zones. It shelters rare species of flora and fauna. It also includes many archaeological sites, Calakmul being the most important one. This pre-Colombian city has been registered on the World Heritage List (cultural part) in 2002.

Within recent years, settlement pressure, farming and new extraction of commercial timber caused threats to this natural and cultural heritage. In order to help the Mexican authorities INAH (Instituto Nacional de Antropologia e Historia) and CONANP (Comision Nacional de Areas Naturales Protegidas) to preserve it, UNESCO proposed to make use of Belgian expertise. Accordingly, four research teams were selected and funded by the Belgian Science Policy Office (BELSPO) and formed a consortium in charge of the project.

1.2 *Description.*

The so-called "Development and use of a 4D GIS to support the conservation of the Calakmul site (Mexico, WHP)" project started in December 2007. Following UNESCO requirements, the consortium proposes to develop and implement an "Information Management System" for the conservation authorities of the Biosphere Reserve and Archaeological Urban Centre of Calakmul. This system will allow Mexican managers and scientists to store, share and create interaction between their data, in order to coordinate various actions of conservation, management, planning, monitoring and research undertaken in the area. It will also assist them in their reporting activities and to apply for a nomination ("mixed site") at UNESCO in the framework of the World Heritage Convention.

2 4D GIS.

2.1 *Concept.*

The present project is based on the use of new technology and scientific developments for the conservation of natural and cultural heritage. Thus it will benefit from new developments in the GeoICT, Archaeomatic and Spatio-temporal Analysis, Computer Vision and Earth Observation fields.

The information management system will indeed be an online tool integrating 2D GIS layers and 3D objects, large and small scales layers and time.

To do so it will use recent advancements and emerging open standards, but also innovative method and data models to integrate archaeological data and carry out spatio-temporal analysis. It will combine new computer vision techniques to produce 3D models of buildings and works of art from digital photograph sequences. Finally, it will use newly available Formosat 2 satellite images to investigate the possibilities to document Maya ruins: buildings or evidences of man-made structures. This data set, together with SPOT, ASTER and LANDSAT data will also be used to elaborate a land use map of the entire Biosphere Reserve and for change detection.

The information management system will be used as the main data repository to store all data referring to the archaeological inventory, the individual cartography for Calakmul and the cartography of the large nature protection area. This tool will have the following capabilities:

- Manage and visualise data, small and large scale at the time, in 2D and 3D.
- Monitor processes, like eg. the restoration of the site and the land use changes in the surroundings.
- Perform spatial analysis, for the purpose of regional and local planning.
- Facilitate reporting (at national level and towards UNESCO (WHP/MAB...))

As the project has just started, technical choices concerning the system and open standards to be used (eg 2D Map Viewer with time slider coupled with a Content Management System; information models and data formats for 3D GIS: Collada, X3D, CityGML, etc. and OGC WebServices) have still to be taken based on the user requirements analysis. Following this short description of the whole project, we will thus basically focus hereafter on the Cultural Heritage data modelling question and on the use of Earth Observation data for Natural and Cultural Heritage management.

2.2 *GIS, Remote Sensing and World Heritage*

Remote Sensing offers many useful and sometimes indispensable data that can be integrated in a GIS for the mapping, monitoring and management of World Heritage sites, either natural (parks, landscapes...) or cultural (monuments, archaeological sites...). GIS and Remote Sensing are thus excellent tools to support the monitoring process that is required for the good conservation of World Heritage sites (BELSPO, 2002).

With respect to Cultural Heritage and archaeology, as far back as the middle of the eighties, Anglo-Saxon archaeologists were the firsts to take advantage of GIS, especially in a predictive modelling perspective. During the nineties, professionals involved in inventories of Sites and Monuments found in GIS a particularly attractive technology offering a map–based representation of sites' locations. Then came interest for spatial analysis dedicated to archaeological questions (Wheatley & Gillings, 2002).

Having overtook the technological appropriation phase, scientists are henceforth debating about theoretical concepts subtended their researches on GIS. Indeed, initial 2D representation gives way to an increasing involvement of volume and time dimensions, although current GIS vendor solution do not allow such variety of dimensions (Lefebvre, 2006).

On the other hand, it is more and more admitted that, in speaking of the Cultural Heritage domain, the principal challenge lies, not so much in collection or geo-localization or even modelling of the data, but in the manner of processing related non spatial information (Blaise & Dudek, 2006).

In this domain, very high resolution satellite images can be used to monitor archaeological remains or to map large sites not covered by vegetation thus providing valuable information for Cultural Heritage management as well.

With respect to Natural Heritage, remote sensing data can be used to create up-to-date maps even for the most remote and inaccessible places where no recent maps are available. It can help to delimitate management zones and to monitor land cover and vegetation changes caused by natural disaster or human activities.

3 DATA

3.1 Archaeological data

3.1.1 History of discoveries

Inhabited for more than 1500 years, left and even forgotten since the end of the ninth century, the Maya archaeological site of Calakmul was rediscovered in 1931 by an explorer: Cyrus L. Longworth..

The first cycle of real archaeological records took place in 1932, under the supervision of Sylvanus G. Morely, sponsored by the Carnegie Institute. Subsequent researches have been done by several teams. First of them directed their attention to topographical and mapping survey. Excavation operations really began in 1984, with William J. Folan (Universidad Autonoma de Campeche - UACAM), and since 1994 by Ramon V. Carrasco (INAH). To add to this, international teams are nowadays cooperating with Mexican scientists on some specific spots. (Giorgi & alii, 2006; Niccolucci, 2006; Šprajc, 2008).

The results of their works, combined with epigraphic studies, historical analysis and other knowledge domains, shows that we are in front of a very important place. Indeed, during its apogee at the early classic period, Calakmul was the largest city of the Maya region and had to assure its hegemony by any means, peaceful or not. It was a feared jungle chieftain until the end of the seventh century A.D. when Jaguar Paw, king of Calakmul, was defeated after a bloody battle against Tikal, the rival city. From that moment on, began the slow decline of the head snake kingdom (Folan & alii, 2001; Vidal-Angles & Domínguez-Turizza , 2003).

3.1.2 The urban centre

Spread over an area of 30 square kilometres, with more than six thousands archaeological structures, the city appears like a vanished urban centre now covered with vegetation. The core of the town has been built upon a great natural flat-topped hill, partially lain out to base platforms of pyramids, palaces and other temples. Those buildings are split up into several poles: a central place and smaller groups placed in spokes. Oriented along a north-south axis, the central place was a magical space used for ceremonies and rituals. Its north and south sides are occupied by pyramids (Folan & alii, 2001; Vidal-Angles & Domínguez-Turizza, 2003). The biggest one (Structure II, south side) rests upon a 140 meter square base and rises up to 55 m. The west side of the plaza is bordered by what archaeologists think to be an astronomical complex related to the solstices and equinoxes. This function is also taken on by another small building (structure VIII) just near the north side pyramid. The lengthy structure IV, situated on the East Side of the quadrilateral, was possibly associated with administrative and palace matters. In the middle of this rectangle, structure V divides the square into two sections and had ritual functions too. Around that pole, the other groups of buildings are dedicated to ceremonials and civil functions. Well away from that important core, most of archaeological remains have not been excavated yet. However, hydraulic settlements designated to supplying water have been discovered, like other logistical settlements (Vidal-Angles & Domínguez-Turizza, 2003).

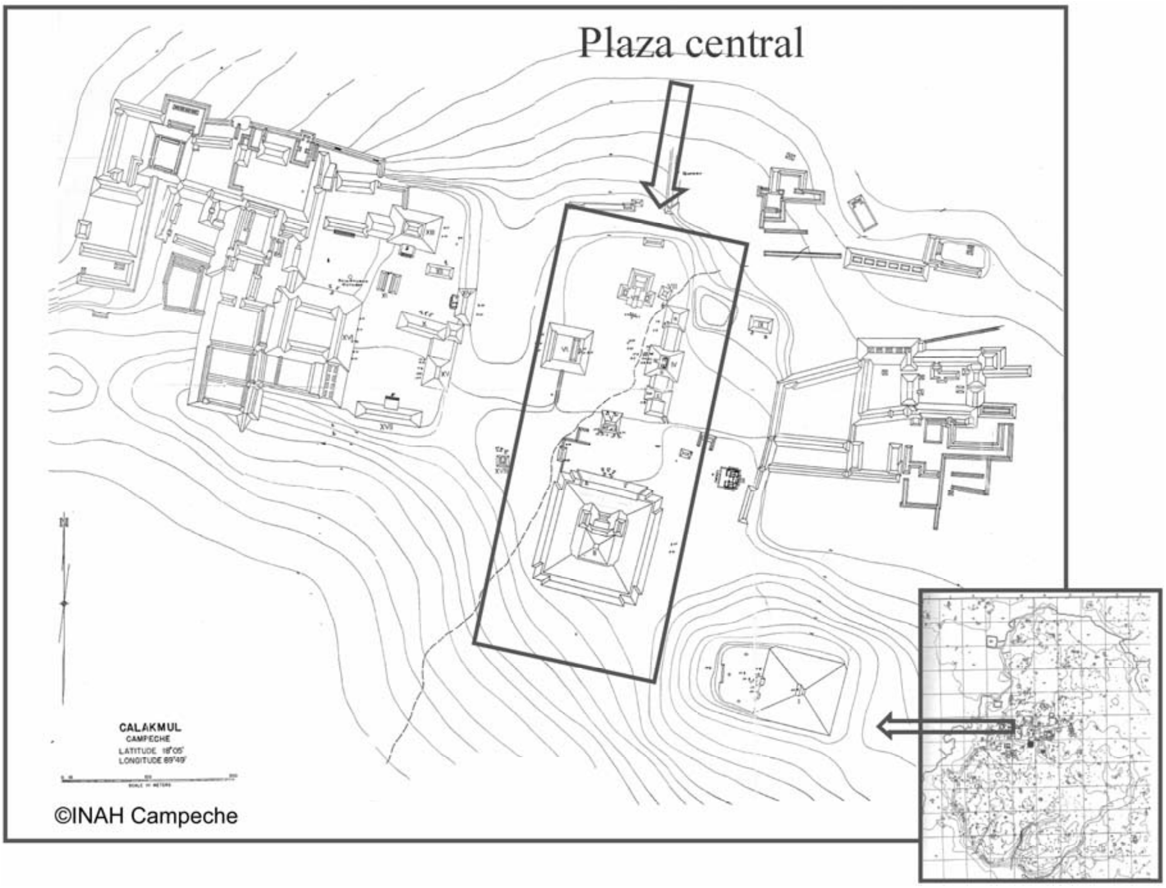


Figure 1 Urban Centre of Calakmul

As it is now, the site remains like it was before its disuse, during the Late Classic period. But the most surprising thing lies under the facades: each monument hides - and fortunately protects - one or more earlier building phases, often magnificently well preserved. On account of this, Calakmul is seen as an unrepeatable witness the daily life of a gone civilization: wall paintings, low reliefs, decorated ceramics depict unexpected scenic aspects like, for example, the funerary rituals.

3.2 *Remote Sensing data*

Thanks to BELSPO financial support, new Formosat 2 images are currently being acquired. Formosat 2 sensor is a new Taiwanese satellite launched in 2004 that offers 24X24 km images with 2m resolution (PAN – 8m MS). This will allow us to obtain the first very high resolution satellite mosaic over the entire reserve. In addition, LANDSAT, SPOT and ASTER archive data will be used.

4 METHODS

4.1 *Models for archaeological data*

To model archaeological data, we have planned to put into practice the scientific protocol recently proposed by H. Galinié, X. Rodier and L. Saligny (Galinié *et al.*, 2004; Rodier & Saligny, 2007). Based on the F. Bouillé's Hypergraph Based Data Structure method (Bouillé, 1977) and the Peuquet's triad (Peuquet, 1994), it requires, using a rigorously formalism, the transformation of heterogeneous data into robust entities (urban objects) delimited by three domains: the spatial, social and temporal features. This method aims at studying urban archaeological contexts, especially to get their dynamics of change. On that goal, it notably suggests avoiding information redundancies.

On the other hand, research about ontology undertaken by computer science and geomatics specialists (Zlatanova, 2000; Billen & Zlatanova, 2003) shows promising results and potential solutions with concepts like juridical, fictional and abstract objects. They should be useful to model data with or without incomplete spatial components. At last, new triangular model (Van De Weghe *et al.*, 2007) for time representation will also be tested.

4.2 *Image processing techniques*

The innovative method chosen here to extract information from satellite imagery is the object-oriented image processing technique. In contrast to traditional image processing methods, the basic processing units of object-based image analysis are image objects or segments, and not single pixels. The classification to produce the land use maps is thus not done on the basis of imagery pixels but on the basis of image objects detected during the segmentation process. This will increase the time-efficiency as well as the potential for products updating since segmentation and classification procedures can be transformed into standardized protocols and stored to be applied to other datasets.

5 CONCLUSIONS

While the main goal of this project consists in elaborating a whole and efficient integrated system combining various data, its major scope concerns Cultural Heritage in all its complexity. To take it into consideration, cooperation with Belgian and Mexican partners, know-how and knowledge transfer, flexibility and cleverness will be necessary. By bringing it to fruition, this project will produce results reusable for other Cultural Heritage sites.

6 REFERENCES

BELSPO, 2002. Remote Sensing and GIS in support of World Heritage Conservation. http://telsat.belspo.be/whp/remotesensing.html

Billen, R., Zlatanova, S. 2003. 3D spatial relationships model: a useful concept for 3D cadastre? *Computers, Environment and Urban Systems,* 27: 411- 425.

Blaise, J.-Y., Dudek, Y. 2006. Modélisation informationnelle: un cadre méthodologique pour représenter des connaissances évolutives spatialisables. *Extraction et Gestion des Connaissances 2006*, vol. 1, *Revue des Nouvelles Technologies de l'Information,* E-6 : 347-358.

Bouille, F. 1977. *Un modèle universel de banque de données simultanément partageable, portable, répartie*. Thèse d'Etat es Science, Université de Paris VI, Paris.

Folan, W.-J., Fletcher, L., May Hau, J., Florey-Folan, L. (coord.) 2001. *Las Ruinas de Calakmul, Campeche, Mexico : Un lugar central y su paisaje cultural*, UAC, CIHS.

Galinié, H., Rodier, X., Saligny, L. 2004. Entités fonctionnelles, entités spatiales et dynamique urbaine dans la longue durée. *Systèmes d'information géographique, archéologie et histoire, Histoire et Mesure* XIX, 3: 223-242.

Giorgi, R., Chelazzi, D., Carrasco, R., Colon, M., Desprat, A., Baglioni, P. 2006. The Maya site of Calakmul : « in situ » preservation of wall paintings and limestone by using nanotechnologies. *IIc congress 2006: proceedings.*

Lefebvre, B. 2006. Construction et déconstruction de l'espace urbain : une modélisation en volume du bâti ancien. *MIA journal* 2, VII. http://www.map.archi.fr/mia/journal/

Niccolucci, F. 2006. On-Site ICT Applications in Archaeology. The Calakmul case. *Proceedings of the EVA London conference*.Peuquet D.-J., 1994. It's about time: a conceptual framework for the representation of temporal dynamics in geographic information systems *Annals of the Association of the American Geographers,* 3: 441-461.

Rodier, X., Saligny, L. 2007. Modélisation des objets urbains pour l'étude des dynamiques urbaines dans la longue durée. *SAGEO 2007, Rencontres internationales Géomatique et territoire*, CdRom. Série : Aménagement du territoire, AgroParisTech-ENGREF Clermont-Ferrand.

Šprajc, I. (ed.) 2008. *Reconocimiento arqueológico en el sureste del estado de Campeche: 1996-2005. BAR International Series* 1742, Paris Monographs in American Archaeology 19, Oxford, Archaeopress.

Van De Weghe, N., Docter, R., De Maeyer, P., Bechtold, B., Ryckbosch, K. 2007. The triangular model as an instrument for visualising and analysing residuality. *Journal of Archaeological Science,* 34: 649-655.

Vidal Angles, C., Domínguez Turizza, M. (coord.) 2003. *Calakmul Anthologia*, Conaculta – INAH, Campeche, Mexico.

Wheatley, D., Gillings, M. 2002. *Spatial Technology and Archaeology, the Archaeological Applications of GIS*, Londres et New York, Taylor & Francis.

Zlatanova, S. 2000. 3D GIS for Urban Development. *Technical Sciences*. Graz Austria, Graz Austria of technology, 222.

7 ACKNOWLEDGEMENTS

The research presented in this paper is carried out in the framework of the "Development and use of a 4D Geographic Information System to support the conservation of the Calakmul site (Mexico)" project which is funded by the international actions program of the Belgian Science Policy Office and supported by UNESCO, INAH, CONANP and UACAM. In addition to ULg and GIM, authors of this publication, this project is carried out in partnership with the Universiteit Gent and the Katholieke Universiteit Leuven.

Integration between high resolution satellite images, GPS and Tablet PC with a new software for archaeological survey: the Ulixes system

G. Di Giacomo[1], G.P. Di Giacomo[2], G. Scardozzi[1]

1 CNR-IBAM. Italian National Research Council – Institute for Archaeological and Monumental Heritage, Strada per Monteroni c/o Campus Universitario, 73100, Lecce (Italy); digiacomogiacomo@yahoo.it, g.scardozzi@ibam.cnr.it
2SIRTER srl, Via Acclavio, 64, 74100 Taranto (Italy); gianpaolo@sirter.it

Keywords Archaeology, GIS, GPS, Software, High Resolution Images.

ABSTRACT.

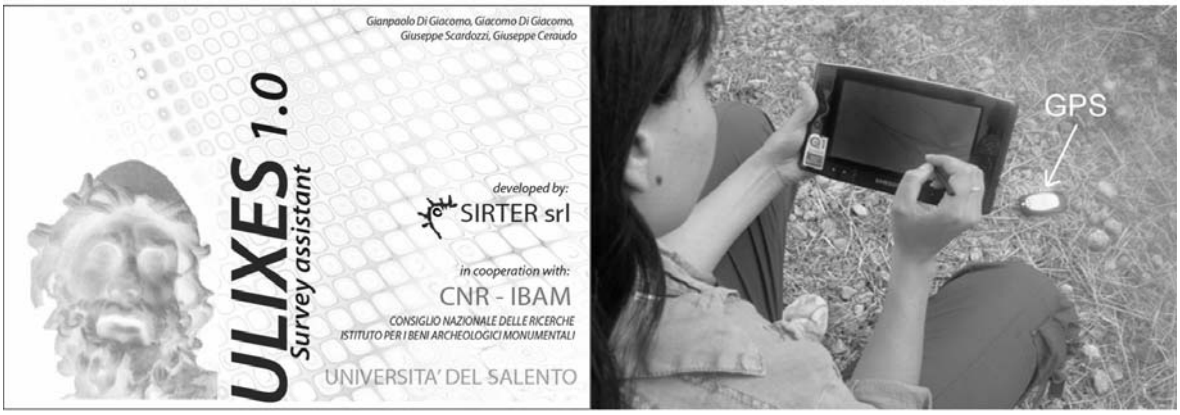
This work presents the results of an experimental system developed to help the archaeological survey, by navigation on cartographies (vectors and raster), vertical aerial photos and high resolution satellite images, visualized on a Tablet PC, which is connected with a GPS receiver. This system, called *Ulixes*, was developed in a collaboration between Institute for Archaeological and Monumental Heritage of the Italian National Research Council (*CNR-IBAM*), the SIRTER company and the Chair of Aerial-Topography of University of Salento; it was tested in 2006 and in 2007, during archaeological surveys.
Ulixes can support any georeferenced cartography, and is able to store a simplified survey schedule. The library of this schedule is created by user before survey, and are upgradeable directly in the field work. This paper contains a brief explanation of philosophy that have guided us during the work. The very important goal of this application is that it is created by archaeologist, and was born for archaeological purpose.

1 INTRODUCTION

In these last years it is possible, by using the high resolution satellites for civil purposes, to fast obtain very detailed images of earth surface, that maybe useful where topographic maps or aerial photos are poor or not so recent: in fact, satellite images are used to upgrade an existent cartography, in the medium-large scale. In archaeology, the use of these images is largely diffused (near the standard cartography), and seems very useful for field work in a survey, because it is a fast way to complete monitoring archaeological areas. These images are digital images in native format; so they became simply useful into personal computer, that archaeologist can use for navigation during the survey, near to the old cartography printed on paper.
In this contribution is present a new software, that work on compact PC, called *Ulixes* (Fig. 1), that was developed and tested in 2006 and in 2007 during archaeological survey in Italy and outside Italy, particularly in Troia (Foggia - Italy) and Hierapolis of Phrygia (Denizli - Turkey); in these areas, the system was tested in association with high resolution images taken by QuickBird satellite, used in panchromatic mode, orthorectified and georeferenced by GCP taken with a topographical GPS (see Di Giacomo, Ditaranto, Scardozzi in this volume). This system was developed by Institute for Archaeological and Monumental Heritage of the Italian National Research Council (CNR-IBAM), the SIRTER company and the Chair of Aerial-Topography of University of Salento; it was tested, during archaeological surveys (Scardozzi, 2007a, 674904/5; Scardozzi, 2007b, 333-336).

2 THE ULIXES SYSTEM

Ulixes system, by a simplified procedure, can support satellite images and can store archaeological survey data into a non-volatile memory. After a processing of the native image, finalized to obtain a georeferenced file in a compatible format for *Ulixes*, when it is ready to use, it is sent to a standard Tablet PC: for our test we have choose a Samsung Ultra Mobile NP-Q1 (Fig. 2), equipped with Windows XP Tablet PC Edition, because this PC have a good resolution monitor and support the touch screen technology (on the use of Tablet PC in archaeological field work see Campana, 2005 and 2006). During the transfer, the *Ulixes* software automatically splits into a grid the entire georeferenced image that user want to use, which is divided into an indexed mosaic of 500 square meters images, stored into a folder, and a file which contains the geocodes to reference each single granule of the mosaic (Fig. 3). If the user want to use a vector map, this one is translated into a GeoTIFF file before the transfer. In the next version, we want to develop a system that is able to use vector file directly.


Gianpaolo Di Giacomo, Giacomo Di Giacomo, Giuseppe Scardozzi, Giuseppe Ceraudo
ULIXES 1.0
Survey assistant
developed by:
SIRTER srl
in cooperation with:
CNR - IBAM
CONSIGLIO NAZIONALE DELLE RICERCHE
ISTITUTO PER I BENI ARCHEOLOGICI MONUMENTALI
UNIVERSITA' DEL SALENTO
GPS

Figures 1 / 2. The splash screen of Ulixes software. The system in use during field work.

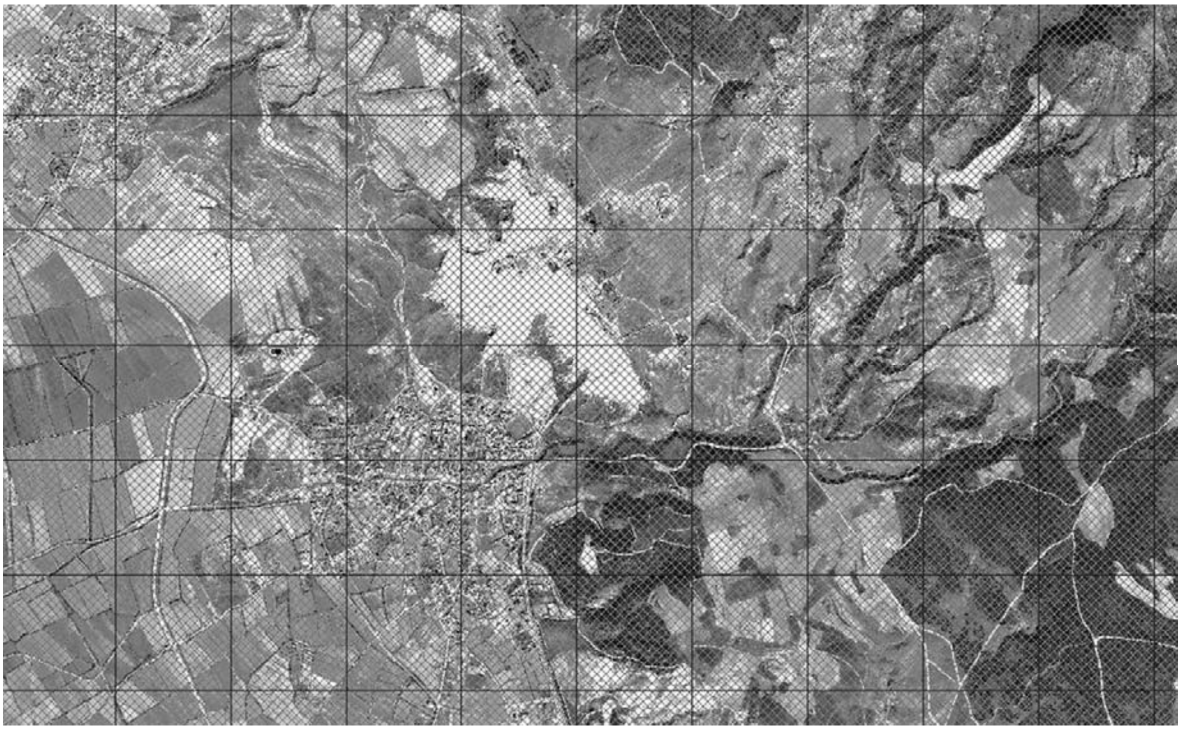
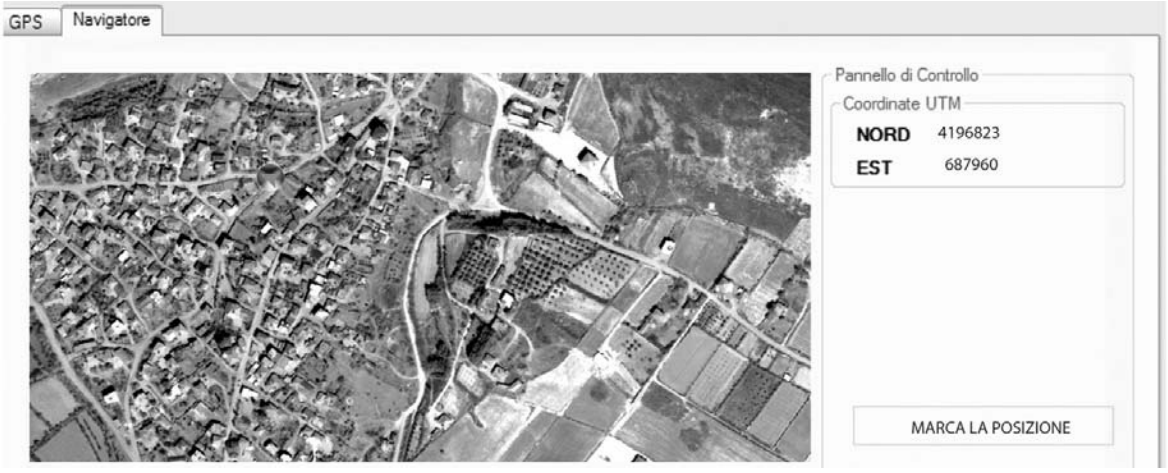


Figure 3. High resolution QuickBird image splitted into indexed georeferenced mosaic of 500 square meters.

However, next step is to create a Bluetooth interface between the Tablet PC and a low cost GPS receiver, by a guided procedure: for our test we have used a 20 channel Hamlet Bluetooth GPS equipped with a Sirf Star III chipset, which output data is in standard NMEA Protocol or in Sirf Binary Protocol. The actual version of *Ulixes* read the NMEA strings: a version capable to read the Sirf Binary is in develop phase. When the GPS is connected to the Tablet PC, *Ulixes* start to calculate position on ground step-by-step, according to the frequency of GPS signal (1 package of data each second) and it is capable to select in real time the correct image in the mosaic of splitted images, searching the index for what image contains the actual coordinates: this image is projected on the monitor (Fig. 4) and is updated each second, and an arrow indicate the position on the map together the bearing of the operator's step. This is possible, obviously, only when the software read two successive data package, so it can calculate the vector that is the result of orientation and motion. On the right of the map, there is a control panel, that lists information such as, for example, the position (expressed in geographic coordinates, WGS84), quote (orthometric), PDOP (Point Diluition of Position), VDOP (Vertical Diluition of Position), and so on.



Pannello di Controllo

Coordinate UTM

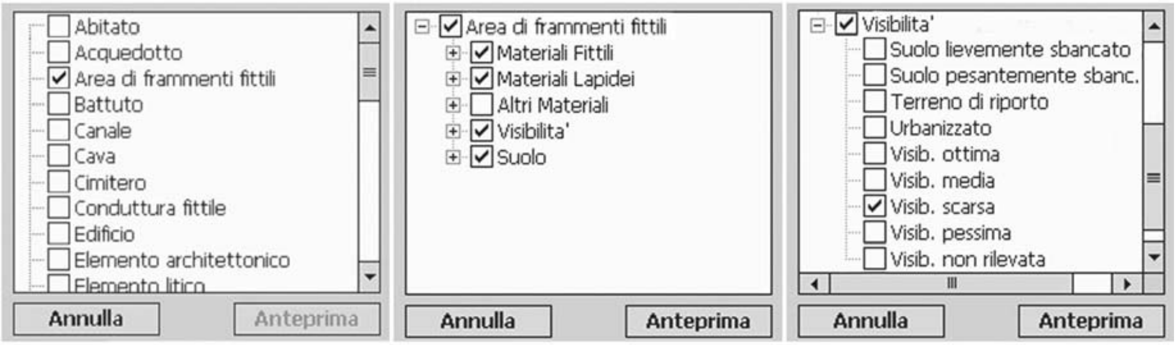
NORD 4196823

EST 687960

Figure 4. The high resolution QuickBird image visualized in the navigation tab.

In the control panel, there is also a button, that is useful when an archaeological find happens: if the archaeologist ask for, the system is able to mark actual position and to link a digital survey schedule to this position. This schedule is expressly created for *Ulixes* system, and the library of archaeological words maybe upgraded and implemented during the survey itself, too.

The schedule is compiled by a tree view form (figure 5) and is wrote into a structured file such as, for example, an *.xml or *.csv, stored into a stable memory, as for example a storage card; in fact, *Ulixes* system, during start up, recognize all memories present in the hardware, and ask to user for what memory it have to use during the survey. If the memory became full during the work, the system close the file and ask to user for a new storage mass in the specified location, or to change location. In the same way, if the battery is low, before the system go down, the file is closed by *Ulixes*. This is a standard procedure to prevent data loss. When the file is closed, it is ready to sent to a GIS on a server or a desktop PC.



- ☐ Abitato
- ☐ Acquedotto
- ☑ Area di frammenti fittili
- ☐ Battuto
- ☐ Canale
- ☐ Cava
- ☐ Cimitero
- ☐ Conduttura fittile
- ☐ Edificio
- ☐ Elemento architettonico
- ☐ Elemento litico

- ☑ Area di frammenti fittili
  - ☑ Materiali Fittili
  - ☑ Materiali Lapidei
  - ☐ Altri Materiali
  - ☑ Visibilita'
  - ☑ Suolo

- ☑ Visibilita'
  - ☐ Suolo lievemente sbancato
  - ☐ Suolo pesantemente sbanc.
  - ☐ Terreno di riporto
  - ☐ Urbanizzato
  - ☐ Visib. ottima
  - ☐ Visib. media
  - ☑ Visib. scarsa
  - ☐ Visib. pessima
  - ☐ Visib. non rilevata

Figure 5. The tree view system to compile the archaeological schedule.

This system is oriented to simplify and to perform the operations of fast documentation of the archaeological elements and storing data during the survey, but also it is very useful to upgrade in real time the databases of an archaeological GIS previously created.

Another interesting function of this system is the capability to record the track of the survey, which is very useful if someone need to came back to an archaeological find. This function is useful also if any track on the satellite images is founded: in fact, is possible sign on the image a point of interest, and the system is capable to drive the user to this point.

Therefore, at this point of develop the system is not able to use the Disjkra algorithm to calculate the way, so it calculate the vector that link your position with your point of interest: it means that the way calculated by software is not ever the best way to came to your target. This limit is connected to the actual version of Ulixes, that not support vector format: we hope that the next version of Ulixes (that now we are developing), is oriented to support the algorithm for best way calculation.

3 CONCLUSIONS

The tests of the *Ulixes* system, in different conditions, have demonstrated its utility to lighten and accelerate the task of positioning and managing the archaeological finds during archaeological survey. When the system will be complete, it maybe a solution to store digital surveying data, for monitoring well-known archaeological area, and to acquire new data. Finally, the very important goal of this application is that it is created by archaeologist, and was born for archaeological purpose.

4 ACKNOWLEDGEMENTS

For their constant support and the interest with which he has followed the development of *Ulixes* system, we thank Prof. Francesco D'Andria, Director of the Italian Archaeological Mission and of CNR-IBAM, and Prof. Giuseppe Ceraudo, chair of Archaeological Aerotopography in University of Salento.

5 REFERENCES

Campana, S. 2005. Lavoro sul campo: sistemi di georeferenziazione satellitare GPS e computer mobili, in Musson C., Palmer R., Campana S. (a cura di), *In volo nel passato. Aerofotografia e cartografia archeologica*, Firenze, 255-259.

Campana S. 2006. DGPS e Mobile GPS per l'archeologia dei paesaggi, in Campana, S., Francovich, R., *Laser scanner e GPS. Paesaggi archeologici e tecnologie digitali, 1*, Firenze, 201-225.

Scardozzi, G. 2007a. Remote sensing and archaeological survey in the Hierapolis of Phrygia territory, Turkey, in *Remote Sensing for Environmental Monitoring, GIS Applications, and Geology*, Conference 6749 *"Remote Sensing and Archaeology"* (Florence Monday - Thursday 17-20 September 2007) - Proceedings of SPIE Europe Remote Sensing, Vol. 6749, 674904/1-12.

Scardozzi, G. 2007b. Hierapolis di Frigia. Applicazioni informatiche alle ricognizioni archeologiche e telerilevamento da satellite: l'esempio degli acquedotti della città, in Scardozzi, G. (a cura di), *Progetto FIRB 2001 "Il Mediterraneo antico e medievale come luogo di incontro tra Oriente e Occidente, Nord e Sud"*. Atti della Giornata studio sul tema "GIS e applicazioni informatiche alle ricerche archeologiche e storiche" (Roma, CNR, 5 luglio 2007), *Archeologia e Calcolatori*, 18: 331-353.

Multitemporal remote sensing data for the knowledge and the monitoring of Iraqi archaeological sites

G. Scardozzi
CNR-IBAM, Italian National Research Council – Institute for Archaeological and Monumental Heritage, Strada per Monteroni c/o Campus Universitario, 73100 Lecce (Italy); g.scardozzi@ibam.cnr.it

Keywords: Archaeology, Monitoring, Iraq, Multitemporal, High Resolution Images.

ABSTRACT.

The paper concerns a part of the activity of Institute for Archaeological and Monumental Heritage (CNR-IBAM) in the *Iraq Virtual Museum* Project of the Italian National Research Council; particularly, it is focused on the activities for the realization of the section “Archaeological Sites”, finalized to the contestualization of finds stored into the Baghdad Museum. During this work was very important the contribution of high resolution satellite images (Ikonos-2, QuickBird-2, WorldView-1), taken in 2002-2008 and used to document the modern situation of the archaeological areas and for monitoring their pre-post second Gulf War situations; very important were also the high resolutions satellite photos taken by USA spy satellites in 1960s and 1970s, that are useful for monitoring the transformations of the most important archaeological Iraqi areas in the last 30-40 years, before the first Gulf War. The remote sensing data used in the Project for the contestualization of archaeological finds, also allowed to discover new data about ancient topography, urban layout and palaeo-environmental context of much ancient cities and archaeological areas; for the study of these sites and territories are also used some aerial photos taken in 1920s, 1930s and 1940s by RAF pilots. In some cases, instead, the ortho-rectify of the recent satellite images and the vectorialization of all archaeological remains and traces visible in “historical” and modern satellite images, allowed the upgrade of archaeological existing maps with new data about ancient urban plans, monuments and roads.

1 INTRODUCTION

In the *Iraq Virtual Museum (IVM)* Project, conducted by the Italian National Research Council, whose objective was the construction of a Virtual Museum of the ancient civilizations that flourished in the territory of Iraq, the activities of Institute for Archaeological and Monumental Heritage (CNR-IBAM) are focused to the realization of the virtual tour in the most important archaeological Iraqi sites, and to the contestualization of finds stored into the Baghdad Museum; in fact, is very important to link them to their sites of provenance. For each chronological section of the Virtual Museum, were chosen two or three archaeological sites more representative, and they were documented by cataloguing the most significant monuments, in terms of historical and topographical development, in order to provide the “visitor” to the Virtual Museum with a complete image of the characteristics of the contexts where the artefacts were found. In few cases, some monuments or cities plans have been reconstructed by means of 3D image-based modelling and rendering (see Gabellone, Scardozzi 2006 and 2007; Cultraro, Gabellone, Scardozzi 2007 and in this volume). So, in these activities are integrated humanistic approaches (historical sources and archaeological data from old and recent excavations) and recent scientific methods and technologies, specifically, archaeological satellite remote sensing and image-based 3D modelling (photo-modelling and digital photogrammetry).

Particularly, this paper concerns the very important contribution of the utilization of high resolution satellite images in the section “Archaeological Sites” of the *IVM* Project. First of all, the images were used to document the modern situations of ancient sites and for monitoring their condictions before and after first and second Gulf War (for another archaeological project concerning the study and monitoring of an ancient Mesopotamian city, see Invernizzi *et al.* 2007). For each site were acquired multitemporal remote sensing data, such as recent images of civil satellites (Ikonos-2, QuickBird-2, WorldView-1) taken in 2002-2008 and high resolution satellite photos taken by USA spy satellites (Corona KH-4A and KH-4B, Gambit KH-7 and Hexagon KH-9) in 1965-1979. In fact, the availability of satellite images with high geometric resolution has opened up new possibilities for archaeological research and represents a form of documentation with enormous potential for the study of urban and territorial contexts. These images make it possible to observe and document the archaeological areas as they are today, both as a substitute for a real visit (currently impossible), and in preparation for a visit in the future. The detailed examination of these images also constitutes an important opportunity to acquire new data about the topographical layout of the sites and their principal monuments. In a few cases, for the study of the sites were also used some aerial photos taken in 1920s, 1930s and 1940s by Royal Air Force.

2 REMOTE SENSING DATA AND METHODOLOGY

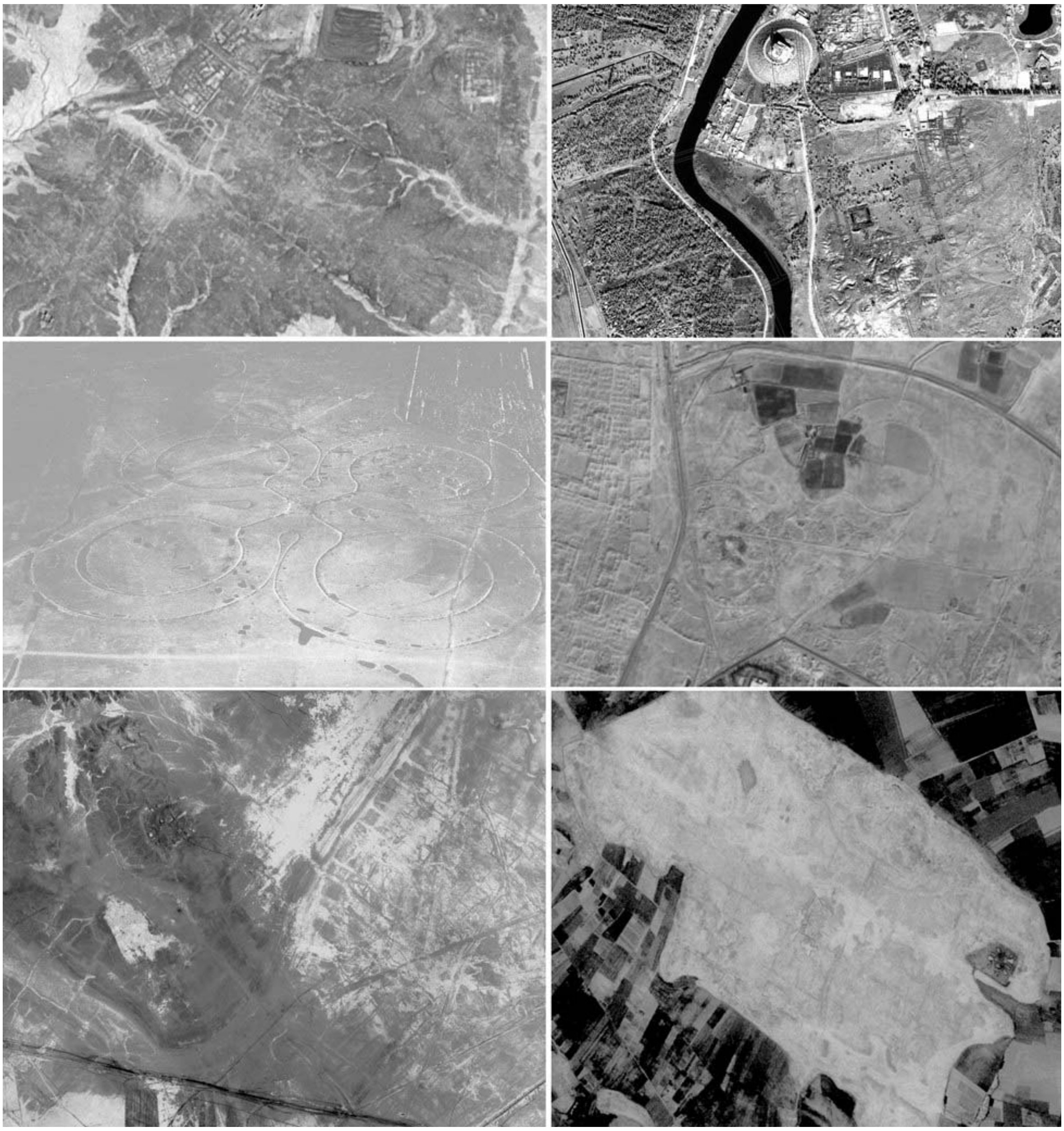
The process of contextualization of the objects in the *Iraq Virtual Museum*, enabling the museum “visitors” to view the original territorial contexts of the finds, can be implemented on three temporal levels: the ancient period, the moment of the discovery and modern times. For the first two the virtual reconstructions, including those based on excavation photos, yield excellent results. Concerning the third temporal level, allowing a virtual visit to the place of provenance in its current situation, the photographic images, both aerial and from the ground, allow the user to view the archaeological areas with a very high detail. Considerable problems arise however in situations where the contexts are not easily accessible and adequate photographic documentation is not available. This is the case of much ancient cities and settlements of Iraq; generally, only few terrestrial images and some oblique aerial photographs of limited parts of the archaeological areas are available, together with some documents (graphic and photographic) of the excavations. An important contribution to the resolution of this problem, as well as to the recovery of documentation that serves to complement any photographic material that may be available, has been provided by high resolution satellite images.

So, in the context of the research activities carried out for the presentation and the creation of the virtual visit of the principal archaeological Iraqi sites, are acquired a few high resolution satellite images. They show some of the most important ancient cities and settlements of Mesopotamia (from Prehistoric times to the Islamic period), such as Ur, Uruk, Tell Es-Sawwan, Tell Asmar, Ashur, Nimrud, Khorsabad, Nineveh, Babylon, Sippar, Kish, Seleucia on the Tigris, Ctesiphon, Hatra, Baghdad, Samarra and Ukhaydir. These images, in panchromatic and multispectral mode, are taken by the commercial satellites Ikonos-2 and QuickBird-2; when it was possible, images taken before and after the second Gulf War were used for each archaeological site; they have a geometric resolution respectively of 1 and 0.60 m in panchromatic mode and 4 and 2.40 m in multispectral mode (*Carterra Geo Ortho kit* and *Standard Ortho-ready* products, with re-sampled pixels dimension). The data have a radiometric resolution of 11 bits, corresponding to a maximum of 2^{11}, i.e. 2048 levels for each band. For some ancient cities, such as Ur, Ctesiphon and Nineveh, were acquired *Standard Ortho-ready* images of WorldView-1 (radiometric resolution of 11 bits), the commercial satellite that transmits images with the highest geometric resolution (0.50 m) in panchromatic mode (www.digitalglobe.com); the satellite was launched in 18th of September 2007, and its images are sold from January of 2008. Moreover, for Ur, Ashur, Nineveh, Khorsabad, Baghdad and Samarra were downloaded QuickBird-2 pan-sharpened images visible in Google Earth.

These images were taken from commercial satellites between 2002 and 2008, so constitute a numerous and up-date documentation, very useful for the study and presentation of archaeological sites and monitoring their transformations in the last years. Their high geometric, spectral and radiometric resolutions are sufficient for them to be used for detailed archaeological research; particularly, their very high spatial resolution makes them similar, in terms of definition, to vertical aerial photographs on a middle scale, that for the studied areas are scarce. These images also make it possible to deepen the knowledge of the ancient sites and to discover new data about ancient topography, urban layout and palaeo-environmental contexts, critical for the reconstruction of the historic landscape in which the ancient settlements were situated. The images make it possible to obtain a detailed view from above of the current state of the remains of the sites and their layouts, given the possibility of noticing even quite small details, enables us to identify elements that are not easily perceptible on the ground and to recognize the traces of structures that are still buried or have become buried again since their original excavation. The processing of the multispectral images of Ikonos-2 and QuickBird-2, in which the measured radiation is divided in four bands including the spectrum of the visible and near infra-red, and the data fusion between panchromatic images and multispectral elaborations have also make it possible to individuate and highlight, in a better way, archaeological and palaeo-environmental traces and anomalies.

In the times of war, satellite images provide a crucial and invaluable tool for monitoring archaeological sites as well as their preservation or damage. For a documentation of the situation before the first Gulf War and also chronological nearer the times of the archaeological excavations, are acquired a few images of 1960s and 1970s taken from United States reconnaissance satellite and, in some cases, aerial photos taken in 1920s, 1930s and 1940s by Royal Air Force pilots. These images are very important, because allowed to discover many data about territories that usually appear developed and have been partially modified and altered.

Particularly, the documentation of USA spy satellite covers all the sites studied; they are numerous panchromatic photos taken in 1965-1979 from cameras KH-4A and KH-4B on board of Corona satellite, and from cameras KH-7 and KH-9 on board respectively of Gambit and Hexagon. These images were declassified and have been publicly available from 1996 (Corona) and from 2002 (Gambit and Hexagon) and are a fundamental tool for archaeological research, very useful when old aerial photos are scarce. In fact, tanks their high geometric resolution, allow to examine in detail ancient urban areas and territories that later are changed or also partially destroyed; so, it is possible to detect and examine ancient structures, palaeo-environmental elements and archaeological traces of buried features not yet visible. Particularly, Corona KH-4A and KH-4B, used from August 1963 to October 1969 and from September 1967 to May 1972, have best spatial resolutions of about 2.70 and 1.80 m; reconnaissance satellites Gambit KH-7, used from July 1963 to June 1967, have an initial resolution of 1.20 m and improved to 0.60 m by 1966; finally, the Hexagon KH-9 systems (March 1973 - October 1980) have a geometric resolution between 6 and 9 m.



Figures 1/6. 1) Pan-sharpened QuickBird-2 image of UR (10-08-2004) with traces of buildings and street near the Neo-Babylonian Houses. 2) Orthorectified panchromatic Ikonos-2 image of Babylon (23-12-2002) with vectorialization of archaeological presences and traces. 3) Aerial photo taken in 1936 by RAF in which is visible the Samarra hippodrome, now partially destroyed by modern urbanization. 4) Pan-sharpened QuickBird-2 image of the Samarra hippodrome (06-01-2005). 5) Panchromatic QuickBird-2 image of Uruk (10-08-2002), with the traces of ancient canals in the territory immediately outside the city wall. 6) Satellite photo taken in 16-08-1968 by Corona KH-4B in which are clearly visible the traces of the insulae of Seleucia on the Tigris.

3 PRELIMINARY RESULTS AND RESEARCH PERSPECTIVES

The reading and detailed examination of the multitemporal high resolution images of the ancient cities of Iraq (still in progress), fundamental in order to be able to correctly “narrate” the sites under study, also constitute an important opportunity to acquire new data about ancient topography, specifically concerning contexts that have been studied many years ago or that are characterized by an history of study centred above all on individual monuments or a wealth of finds. In the analysis of satellite images is very important verify to ground the presences, traces and anomalies visible in the remote sensing data, in order to specify their real pertinence to archaeological elements, the interpretation and, if possible, also the chronology, avoiding misunderstandings and mistakes. But in the study cases of the IVM Project, the ground control with a survey of the sites is impossible, so we can often formulate only hypotheses and the only confront is with published studies.

During the activities of the Project, the study and analysis of high resolution satellite images make it possible to obtain a detailed view of the current situation of the remains of the archaeological sites and their layouts, and also to recover interesting elements for the reconstruction of their ancient topography. Multitemporal remote sensing data have made it also possible to acquire new knowledge of the monuments and the urban and territorial contexts, making it possible to reconstruct the historical landscapes. In some cases, such as in the Neo-Babylonian Houses of Ur, was possible to integrate the excavations areas with traces visible in the satellite images; in other cases, such as immediately surrounding Uruk, are visible the traces of ancient channels now buried. In few cases, moreover, the analysis of the images have also highlighted traces of ancient roads and palaeo-river beds.

These images provide plan views of the archaeological areas, that are very useful for the sites where excavations were focused only on single monuments, edifices or complex and the studies have not interested the general layout of the settlement; in these cases, they make available a complete image of the sites, where different monuments and archaeological areas are together integrated and correctly localized. So were possible to upgrade the archaeological plans of the sites and to realize a vectorial documentation utilized for 3D reconstructions of monuments and ancient cities (such as, for example, Khorsabad and Hatra; see Cultraro, Gabellone, Scardozzi in this volume). In some case (for example Hatra, Babylon, Seleucia, Sippar and Samarra), instead, the recent satellite images were orthorectified without Ground Control Points on DEMs based on SRTM data; the vectorialization of all archaeological remains and traces visible in all multitemporal remote sensing data, allowed the creations of archaeological maps (ready for the input in a GIS) with new data about ancient layout of sites, monuments and roads. Finally, all this documentation elaborated for the *IVM* Project (processed satellite images and photos, new archaeological plans, reports of the data derived from the analysis of the images), can will be collected in an “Atlas” where is highlight the contribution of multitemporal remote sensing data for the study and for the reconstruction of the archaeological sites of Mesopotamia.

4 ACKNOWLEDGEMENTS

For his constant support in the research activities, special thanks go to Dr. Massimo Cultraro, scientific coordinator of the *Iraq Virtual Museum*. In the team of CNR-IBAM that work in the Project *IVM* for the study of the archaeological sites and the processing of the satellite images are Doctors Laura Castrianni, Giacomo Di Giacomo, Imma Ditaranto, Fabrizio Ghio and Giuseppe Pellino.

5 REFERENCES

Cultraro, M., Gabellone, F., Scardozzi, G. 2007. Integrated methodologies and technologies for the reconstructive study of Dur-Sharrukin (Iraq), in *AntiCIPAting the future of the cultural past.* Proceedings of the XXI International Symposium CIPA 2007, (Zappeion Megaron, Athens, Greece 01-06 October), vol. I, 253-258.

Gabellone, F., Scardozzi, G. 2006. Integrated technologies for the reconstructive study of Mesopotamian cultural heritage: the cases of Ur, Uruk and Nimrud, in Proceedings of the International Congress *“Cultural Heritage and New Technologies”*, Workshop 11 - Archäologie und Computer, October 18-20 2006, Vienna, CD-ROM.

Gabellone, F., Scardozzi, G. 2007. From the object to the territory: image-based technologies and remote sensing for the reconstruction of ancient contexts, in Moscati, P., *Virtual Museums and Archaeology*, *Archeologia e Calcolatori.* Supplemento 1, 123-142.

Invernizzi, A., Jahjah, M., Parapetti, R., Ulivieri, C. 2007, Archaeological remote sensing application pre-post war situation of Babylon archaeological site – Iraq, *Acta Astronautica*, 61: 121-130.

GIS applications for recovery and management of historical-architectonic heritage: case study of Tursi-Rabatana medieval site (southern Italy)

M. Lazzari, M. Danese, N. Masini

C.N.R.–I.B.A.M. C/da S. Loja Zona Industriale Tito Scalo (PZ) 85050, Italy. E-Mail: m.lazzari@ibam.cnr.it; m.danese@ibam.cnr.it; n.masini@ibam.cn.it

Keywords: GIS, historical-architectonic heritage, Rabatana, Basilicata, Southern Italy.

ABSTRACT.

This work, carried out with an integrated methodological approach, represents an effort to evaluate the state of conservation of the ancient palaces, characterized by an architectural structure and a constructive culture, through their field-survey and analysis in a GIS platform with the main aim to detect the priorities of intervention for their structural recovery and management.

1 INTRODUCTION

Tursi and its medieval citadel called “Rabatana” is one of the sites most representative of the cultural heritage of Basilicata (southern Italy). Geographically, the site selected for this study is located in the southwestern sector of the Basilicata region (40°15′ and 40°18′ N and 16°14′ and 16° 17′ E) at an average altitude of 310 m above sea level along the hydrographic watershed between the Agri and Sinni main rivers (Fig. 1). The Rabatana’s slopes are very steep and characterized by very intense erosional phenomena (rockfall and mudflows, deep gullies and rills, badlands, pipes), which affect the whole perimeter of urban settlements, threatening the conservation of the site.

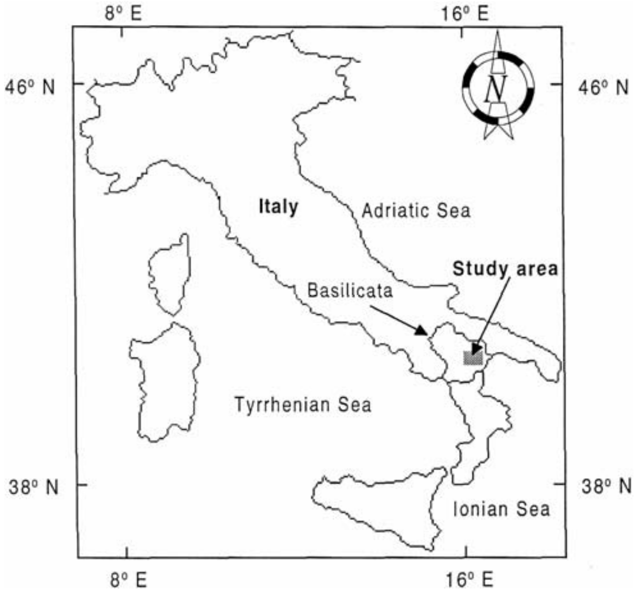


Figure 1 – Geographic location of the study area.

The preservation of Rabatana historical site has always been closely linked to hydrogeological and landsliding problems that affect the surrounding very steep slopes on which several buildings are located (figure 2). Moreover, during the last two centuries the geomorphological hazard conditions have been accentuated by an intense and exacerbated human activity of caves excavation developed along several fronts beneath the urban area. The interaction between human activity and the characters of the natural environment were the reasons of a progressive increase in hazard and vulnerability levels of this site (Lazzari *et al.*, 2006). In fact, cave excavation accelerated the pre-existing morphological processes characterized by widespread surface piping erosion of sandy bodies.

Since 1973 (regional law n° 73 of 29/9/72 and law n°140 of 31/3/1904), this site has been also subjected to the evacuation of its inhabitants in a new urban site due to catastrophic landslides caused by intense rainfalls that occurred on January 1972. Starting from 1974, the Rabatana has been almost completely deserted.

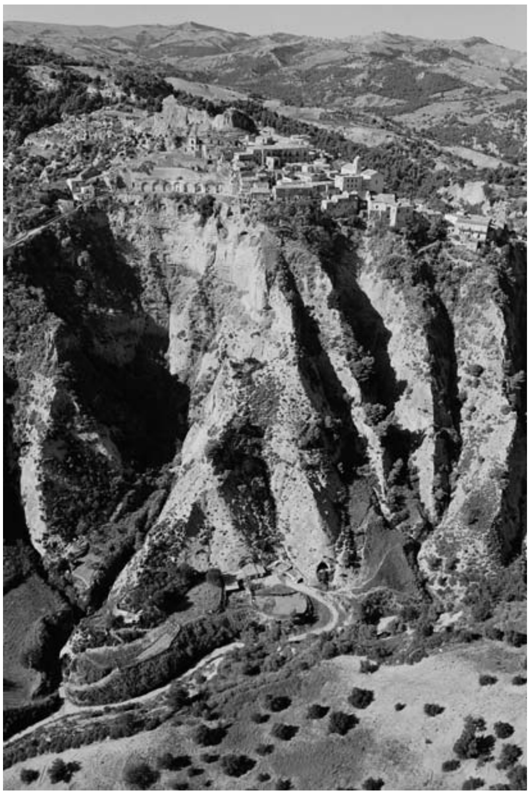


Figure 2 – Panoramic view of the Rabatana medieval citadel and morphological feature of landscape.

Recently, a renewed interest for this site has been developed to recover the historical center, removing the current constraint of total evacuation (Lazzari & Zotta, 2007). However at present, the site is still characterized by a particular morphological history and environmental factors that generate widespread risk conditions for the inhabitants and built-up areas.

2 ARCHITECTONICAL ANALYSIS AND GIS APPLICATIONS

All the calamitous events occurred during last thirty years (landslides, earthquakes, floods) have rendered a lot of the most important ancient palaces of the Rabatana (characterized by numerous constructive elements datable between 1500 and 1800) not fit for use.

The degradation of the constructive materials is mainly due to the deteriorating action of the weather agents, whose effects have assumed a remarkable importance in the last decade because of the maintenance lack, after the abandonment of the urban site. Moreover, an important role has been also played by the earthquake occurred on November 1980.

The first phase of the work has been focused on census and analysis the buildings characterized by particular artistic, historical, aesthetic value and constructive culture. These value elements, such as loggia, balconies, chimneys, cornices, windows, portals, external scales, vaults, arcs and ligneous covers. Moreover, for each single building a specific form has been made in which several information have been inserted, such as the name, age, conservation state (restructured, good, mediocre, bad, very bad, ruin), floor numbers, planimetry, single constructive typologies, photos, constructive elements, metric data, materials, morphology and decorative details, have been aggregates for typology classes, georeferenced and inserted in a geodatabase. Afterward, a qualitative and quantitative analysis have been carried out using ArcGIS software by producing, respectively, a typological emergencies map and a typology quality map.

The typological emergencies map was built using surveyed information, inserted in a geodatabase, on each building of Rabatana, considering all the typological elements characterized by constructive and aesthetic historical value. The total number of these elements (Σn_{tot}) for each building has been divided for the external lateral surface $A_{(m^2)}$. In this way it has been possible to calculate the number of constructive elements found for surface unit, *Ec* (figure 3):

$$E_c = \frac{\Sigma n_{tot}}{A_{(m^2)}} \qquad (1)$$

The typological quality map was built considering the total number of typologies surveyed (Σn_{tip}), characterized by constructive and aesthetic historical value, for surface unit $A_{(m^2)}$, E_t (Fig. 3):

$$E_t = \frac{\Sigma\ n_{tip}}{A_{(m^2)}} \qquad (2)$$

3 CONCLUSIONS

The two thematic maps, in which the results of census and field architectonic survey carried out on the whole ancient urban site of Rabatana are represented, have been compared and overlapped with the buildings surveyed and protected from1980 by the Monuments and Fine Arts Office of Basilicata (Curari Palace, Labriola Palace, Santagata Palace, Spinelli Palace, Donnaperna Palace, Fusco Palace, Tarsia Palace, Church of Santa Maria Maggiore).

The overlapping of informative levels coming of typological quality map, typological emergencies map, state of conservation map and buildings protected from Monuments and Fine Arts Office of Basilicata (table 1 and figure 3), has permitted to evidence that several building not still subjected to protection need of urgent structural interventions in order to avoid their definitive loss.

Buildings	**Buildings protected by the Monuments and Fine Arts Office of Basilicata**	**N° typologies**	**State of conservation**
1	-	11	Very bad
2	-	0	Very bad
3	-	6	Good , mediocre
4	-	8	Bad
5	-	4	Bad
6	-	4	Bad, mediocre
7	-	3	Restored, mediocre
8	-	6	Restored, mediocre
9	*Labriola Palace*	19	Very bad
10	*Cucari Palace*	3	Restored
11	*Santa Maria Maggiore Church*	16	Restored
12	*Spinelli and Santagata Palaces,*	2	Very bad
13	*Traditional buildings*	0	Restored, ruin
14	-	2	Bad
15	*Traditional buildings*	0	Very bad
16	-	3	Mediocre
17	*Donnaperna Palace*	3	Mediocre
18	-	2	Mediocre
19	*Fusco Palace*	12	Very bad, mediocre, bad
20	*Tarsia Palace*	7	Very bad, mediocre, bad
21	-	4	Mediocre
22	-	0	Mediocre

Table 1 –Synthesis of typological constructive elements surveyed for each building and their state of conservation.

In conclusion, the use of an integrated cognitive approach for definition of the historical-artistic and architectonic values of the Rabatana historical site, implemented in a GIS platform, it has allowed to verify the priorities of eventual interventions of recovery and conservation of the buildings analyzed, than are partially different from those indicated from the Monuments and Fine Arts Office of Basilicata.

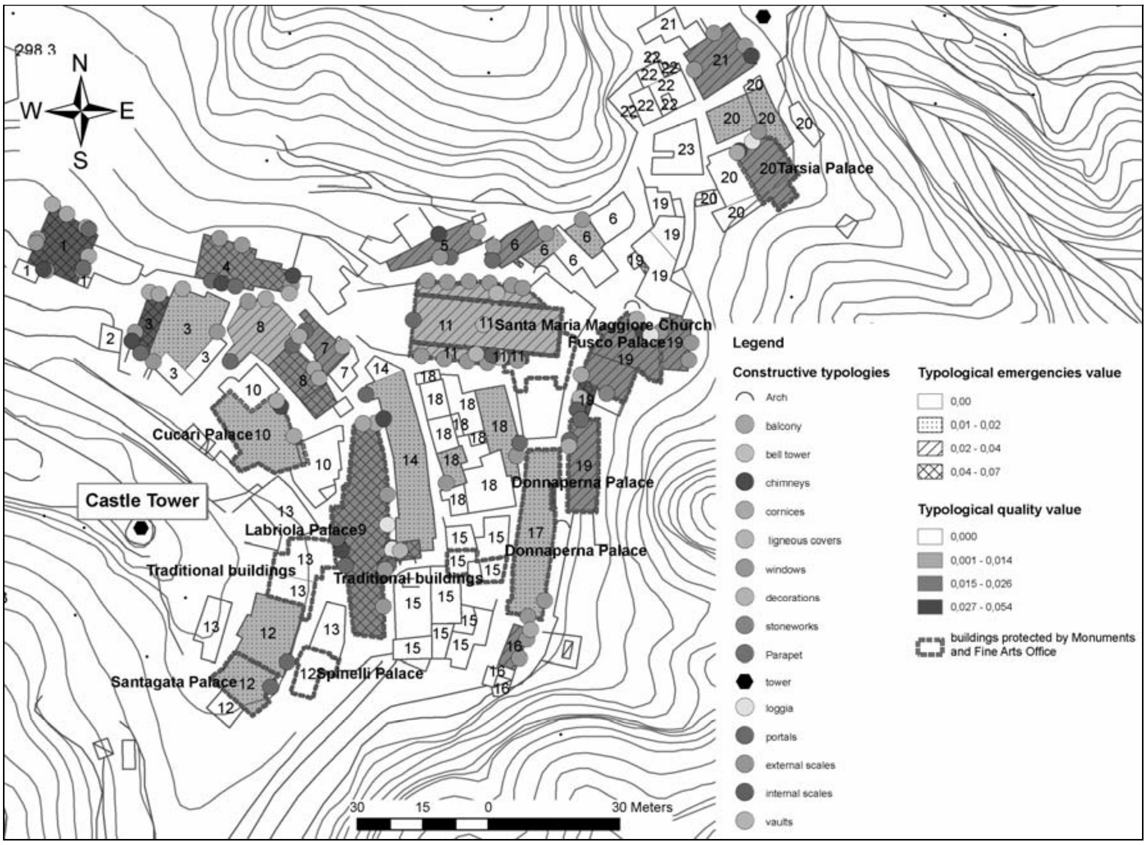


Figure 3 – The overlapping between the typological emergencies and typological quality maps, the main constructive typologies and buildings protected by the Monuments and Fine Arts Office (MFAO) of Basilicata shows that several buildings (1, 4, 3, 5, 6, 7, 8, etc) are characterized by the presence of high number of constructive elements and high quality value but they are not still protected and included in the MFAO list

This method would allow to better address economic budgets oriented to interventions of recovery of the ancient buildings, being based either on the data objectively surveyed with a census or on thematic derived cartography, such as the typological quality map, typological emergencies map and state of conservation map, all expressions of the real conditions of degradation and vulnerability of the site.

4 REFERENCES

Lazzari, M., Zotta, C. 2007. Utilizzo del GIS nella valutazione del rischio geomorfologico ed il recupero del patrimonio storico-architettonico: un approccio integrato per lo svincolo di trasferimento totale della Rabatana di Tursi (Basilicata). Proceedings of XI Conferenza Nazionale ASITA, 6-9 /11/2007 Torino, pp. 1355-1360.

Lazzari, M., Geraldi, E., Lapenna, V., Loperte, A., 2006. Natural hazards vs human impact: an integrated methodological approach in geomorphological risk assessing on Tursi historical site, southern Italy. *Landslides*, 3 (4): 275-287, Springer-Verlag. ISSN 1612-510x (print)/ 1612-5118 (online).

Masini, N. 2004. Analisi del lessico costruttivo della Rabatana di Tursi un contributo per la redazione di un codice di pratica. In: *Tursi- La Rabatana* a cura di Cosimo Damiano Fonseca, Ed. Altrimedia, Matera, pp.157-211.

Advanced Technologies for Archaeological Documentation: Technological and Educational Aspects

A. Cabuk[1], F. Alanyali[2], F. Ergincan[2], A. Deveci[2], U. Avdan[2], S.N. Cabuk[3]
1 Dept. of Architecture, Anadolu University, 2 Eylul Campus, Eskisehir, Turkey, acabuk@anadolu.edu.tr
2 Anadolu University, Eskisehir, Turkey, falanyali@anadolu.edu.tr, fergincan@anadolu.edu.tr, adeveci@anadolu.edu.tr, uavdan@anadolu.edu.tr

3 Odunpazari Municipality, Eskisehir, Turkey, skarademirler@yahoo.com

Keywords: photogrammetry, geographical information system, archaeological documentation, cultural heritage management

ABSTRACT: Phogrammetry is the science and technology of obtaining reliable and accurate measurements from photographic images to deduce the physical dimension of objects and their surroundings and a special method of map making process which requires various high technology applications. Measurements can be made in two or more photographic images taken from different positions determine the three-dimensional coordinates of points on an object. Terrestrial photogrammetry methods help to obtain precise measurements easily. Moreover, it is usually the unique solution to obtain reliable measurements of inaccessible physical details on buildings. Depending on the recent technological improvements in terrestrial photogrammetry, new fields of applications have emerged. For terrestrial photogrammetry, expert personnel support is highly necessary. Although Turkey is a unique country with its rich archaeological and cultural heritage, expert personnel lack in terrestrial surveys, as well as technical deficiencies, end up with low precision results in these kinds of works. Moreover, inadequate documentation appears to be a great threat for the survival of this heritage for the next generations. Besides, poorly operated terrestrial survey-restoration, documentation and reconstruction works may degrade the cultural heritage . Within this context, terrestrial photogrammetry shows up as an efficient solution. Utilization of high technology methods and products provide accurate, precise and rapid results in documentation of historical and cultural heritage. However, technology itself is not enough. It is as well very necessary to have personnel capable of using these technologies efficiently and keen on handling artistic, historical, structural and juridical sides of the organization rapidly and preciously. To train the mentioned personnel, one of the important steps is to start education programmes on utilization of new technology and methods in terrestrial surveys and other related fields. This paper focuses on the application fields and techniques of terrestrial photogrammetry. It also gives information about the sample study carried out in Patara and Anadolu University Advanced Technologies Department, Master of Cultural Heritage Documentation.

1 INTRODUCTION

Although Turkey is a unique country with its rich archaeological and cultural heritage, limited number of trained field personnel, some problems of precision and accuracy, and inadequacy of the documentation works threaten the survival of this heritage for the next generations. Considering these current threats, the Department of Architecture and the Department of Archaeology of Anadolu University have conducted common works for nearly five years. Within this context, a specific unit was constituted and important documentation projects were started with the participation of professionals from different disciplines. A terrestrial photogrammetry laboratory was developed and equipped with the necessary documentation hardware and software both to conduct these projects and train the personnel of the projects. Currently, the laboratory is equipped with Riegl and Trimble laser scanners, an air vehicle for aerial photogrammetry applications, various survey instruments, real time kinematics GPS hardware and mobile office and mobile laser scanning equipment. With these instruments, Anadolu University is among the best-equipped organisations in Turkey.

2 THE ANCIENT CITY OF PATARA CASE

The team has continued the documentation works in the ancient city of Patara since 2004. Within this project, the ancient lighthouse and the Hurmalik Bath in the city were examined with terrestrial and aerial photogrammetry, geographical information system (GIS), field surveys and laser scanning applications. The ancient city plan was also extracted in GIS environment.

The main processes for the documentation of the ancient buildings mostly included the total station and real-time kinematics GPS based terrestrial and aerial photogrammetry and laser scanning applications. During terrestrial and aerial photogrammetry operations, control points were located on the ground and the buildings and these points were surveyed either with RTK GPS or total station. The images captured with high-resolution cameras were rectified according to these survey results and lastly the architectural drawings were extracted from the rectified images in the office. In the laser scanning method, either reflectors (for RIEGL laser scanner) or spheres (for TRIMBLE laser scanner) were located in the area for different scanning positions. The point clouds obtained after scanning were transferred to the computers and used for the production of both high resolution orthophotos and architectural drawings, as well as 3D modelling and hypothetical reconstruction proposals (Figure 1).

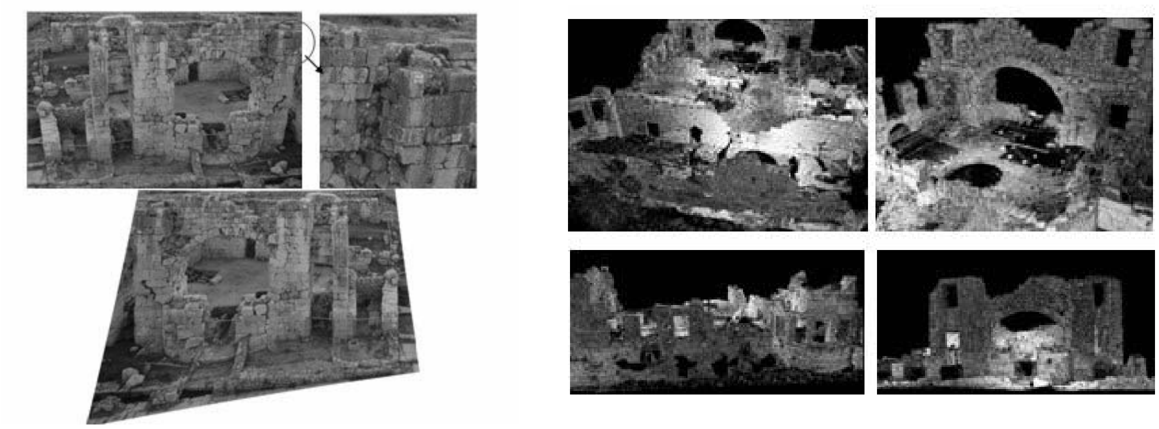


Figure 1. On the left (respectively): Raw images from Patara Hurmalık Bath, control points on the buildings and rectified image. On the right: Images obtained by laser scanning.

3 GRADUATE PROGRAMME

The number of registered protection areas under the responsibility of Culture and Tourism Ministry is 9161, while the number of registered immobile cultural and natural heritage is 81887 (Table 1). This number increases every day as a result of efficient and accurate documentation works. The most important step to protect the country's heritage is to train professionals capable of using advanced technology applications for documentation works. Complete, accurate and permanent documentation is also necessary for monitoring the status of the heritage in time.

Table 1. Registered Heritage Types and Numbers in Turkey

Registered Immobile Cultural and Natural Heritage in Turkey	Number of Immobile Heritage
Civil Architecture Examples	50957
Religious Buildings	7312
Cultural Buildings	7877
Administrative Buildings	1973
Military Buildings	917
Industrial and Commercial Buildings	2796
Graveyards	2479
Martyrdoms	212
Monuments	291
Natural Heritage	5466
Ruins	1560
Protected Streets	47
TOTAL	81887

Considering the trained personnel requirement in the field of advanced documentation, a graduate programme named "Using Advanced Technologies for the Documentation of Cultural Heritage" is started. Within this programme, the documentation is defined as the process of collecting the necessary data using advanced technologies for conservation works. The main aim of the programme is to raise personnel capable of using the advanced technologies to conduct rapid, accurate, precise and efficient documentation projects. The videoconference and virtual class-studio opportunities in Anadolu University also provide distant participation from other universities and academicians during the graduate programme (Figure 2).

Figure 2. Virtual Studio used for distant educational support

Within this programme, the students will be able to study in a multidisciplinary environment. The students will be taught general information on protection theory, material and structure, archaeology and history of art and architecture.

Within the graduate programme, Scientific Preparation Courses will be taken from Architecture, Material Sciences and Engineering, Archaeology Undergraduate, Art History, Remote Sensing and Geographical Information System and Informatics Graduate Programmes. Besides, there will be collaboration between the graduate programmes of Architectural Conservation, Architecture, Art History, Archaeology and Remote Sensing and Geographical Information System. There is not any other similar graduate programme in Turkey and Anadolu University.

Thus, this graduate programme aims to lead the cultural heritage documentation programmes in our country. The students, who are required to take the Scientific Preparation Courses, should take at least four courses or 30 ECTS credits; and at most 8 courses or 60 ECTS credits during one calendar year as scientific preparation courses. The graduate programme includes at least 10 courses, not to be below total 75 ECTS credits, and a term project. Courses of the programme are as follows:

1st TERM		
History and Theories of Conservation	3+0	7,5
Terrestrial Photogrammetry and Laser Scanning	2+2	7,5
Elective Courses (2)[1]	3+0	15
		30
2nd TERM		
Geographic Information Technologies	2+2	7,5
Architecture and Urbanization Approaches in Archaic Age	3+0	7,5
Elective Courses (2)	3+0	15
		30

---

[1] Some of the elective courses: Terrestrial Photogrammetry and Laser Scanning, Geographical Information Technologies, Computer Aided Design, Archaeobotany, Construction History Researches, Archaeometry in the Documentation of Cultural Heritage, Construction Elements in Archaic Age, History of Anatolian Architecture, Special Topics in Conservation, Documentation Methods, Cultural Heritage Management, Conservation Management, The History of Building Culture in Anatolia, Traditional Turkish Architecture, Contemporary Turkish Architecture, Analysis of Construction Material, Natural Construction Material, Safety of Historical Buildings, Protected Areas and Conservation

3rd TERM

Term Project (field study)	3+0	15
Elective Courses (2)	3+0	15
		30

This programme will be supported mostly by the professors of Material Sciences and Engineering, Archaeology, Art History, Architecture departments of the University.

Cultural Heritage management in GIS: cataloguing of ancient marbles in Apulia (Southern Italy).

M. Delli Santi

C.N.R. – I.B.A.M. C/da S. Loya Zona Industriale Tito Scalo (PZ) 85050 Italy, m.dellisanti@ibam.cnr.it

Keywords: GIS, Cultural Heritage, ancient marbles, Apulia.

ABSTRACT.

GIS (Geographical Information System) have been more and more oriented towards the management of many information, that can be – at the same time – aggregated or not and so a valid support for a best choice policy.

The main purpose of this study was the arrangement of a GIS in order to schedule methodically “ancient marbles” in Apulia and in particularly in roman monuments and in the medieval churches of Lecce and its province (Salento). It has been organized so that the common features of handmade stones can be surveyed immediately: for this, indicative schedule in special formats have been drawn up and they should be linked to handmade stones and to vector themes in analysis.

Carried out in this way, the study contains hints for exploitation of territorial development for an organic plan to recover the marble heritage of Apulia.

1 INTRODUCTION

The first aim of an informative system is to make every useful information suitable to the operators who take their choices.

In fact, for almost ten years a larger diffusion of GIS has taken place in scientific and technological field for recovering cultural heritage.

Nevertheless, the tool requests, for its application, practice and knowledge about narrow fields, because it has to monitor spatial – physical situations in accordance with different “angle-shots”: so in this specific study on the cultural heritage about ancient marbles, we shouldn’t leave historical research, surveys and archaeological prospecting, chemical-physical analyses for knowing the degradation state, and also historic-artistic and architectural research on handmade stones that are in the analysed space.

One of the most important role of the research is to use the fundamental technical information that are in GIS as base for drawing up plans to recover and/or consolidate ancient marbles: the simultaneous data, in fact, let us explore various typologies of operations while imagining differentiated results.

2 REUSING ANCIENT MARBLES IN MEDIEVAL CATHEDRALS OF APULIA

Also in Apulia, in the Norman period, we can see, during the building of medieval cathedrals, the spoliation of roman monuments (above all of marbles) and the consequent reusing of the spolio objects in medieval works.

In this article we make point, in particularly, on reusing in the province of Lecce, Taranto and Brindisi (Salento) and above all in Norman cathedrals of Otranto and Taranto and also in roman and medieval monuments of Brindisi and its province.

The Cathedrals of Otranto and Taranto are the buildings in Apulia with the most important examples of reusing techniques of stone materials, at least for the parameters of this work.

In the Cathedral of Otranto the crypt, that was accomplished in 1088, after Normans conquered the city, has sixty-five marble columns and almost all of them are from spoliation and were placed following an extremely coherent course.

The spatial orientation created by the collocation of spolio columns characterizes a precise ideological program that wants to transfer a message of power and political and religious prestige, relating to a new dynasty and a triumphant Latin Church.

The forms and the provenance of reused capitals are various: some are chalice type, which come surely from the Amphitheatre of Lecce of the early half of II century; some are Corinthian, one is composite from Asia, others are Byzantine.

Concerning the Cathedral of Taranto, it began to be built under the Norman Bishop Dragone. The Church was planted above a pre-existent building with continuous hall, with an adaptation following paleochristian models.

3 THE STRUCTURE OF THE GIS

In the analysis by GIS we don't arrive to a mere geometric representation of handmade objects or objects in general: we show, instead, the direct spatial relationships between several elements like connexion, contiguity or inclusion.

Through these relationships, the GIS system will permit – with the arrangement of several but completed data – to define complex analyses of spatial monitoring, showing every time specific elements of *topos.*

In practice, data models, in accordance to an effective interaction, has to foresee the input of description data of every single real object that are definable as spatial indicators.

These three groups of information (geometry, topology, indicators) are interpolated in a GIS by a specific physic model, that nowadays is founded by structures of relationship-data, that are typical of the best databases and by hardware and software *client/server* architectures, in local web: in our case the GIS software that was used for the interpolation and the data management was GENESYS s.h.p..(figure 1).

Generally, the most important phases to elaborate geographical data are:

1. data input
2. data management
3. data analysis
4. data introduction

There will be need distinguishing the typologies of data however. They are divided into two categories:

1. *spatial data* (that is geographical elements position; in our study the medieval monuments in Apulia);
2. *indicative data* (monument, place, period, the name of the ancient marble, ancient stone quarry, provenance) that have to be associated to spatial data.

Spatial data (maps, surveys, etc.) were implemented by manual digitalization, scanning and graphic vector formats; indicative data were introduced by keyboard. In general, all information that were introduced in the GIS come from paper medium, indicative-schedule or internal databases. In fact, indicative data are the result of an historic-urbanistic research, of historic-artistic studies and of other analyses.The spatial data are represented by a vector cartography (scale 1:50.000), that is properly geo-referenced (Gauss-Boaga).

Summarizing, the identification of monuments on relative base cartography has been done according with a point system: the choice of a typology for the "*geotipo",* that is the class of the graphic object, doesn't depend only on its spatial extension, but depends also on foreseen or foreseeable use we want make of every element during data management. After that process indicative-schedules have been drawn up and they have been interactively linked with medieval monuments, so that they fix, on data request through the point system, a detailed class of information about the interested site.

The indicative data have been introduced in an internal database (figure 2): every schedule is linked with a "*geotipo"* by ID connection, that is automatically managed by GENESYS.

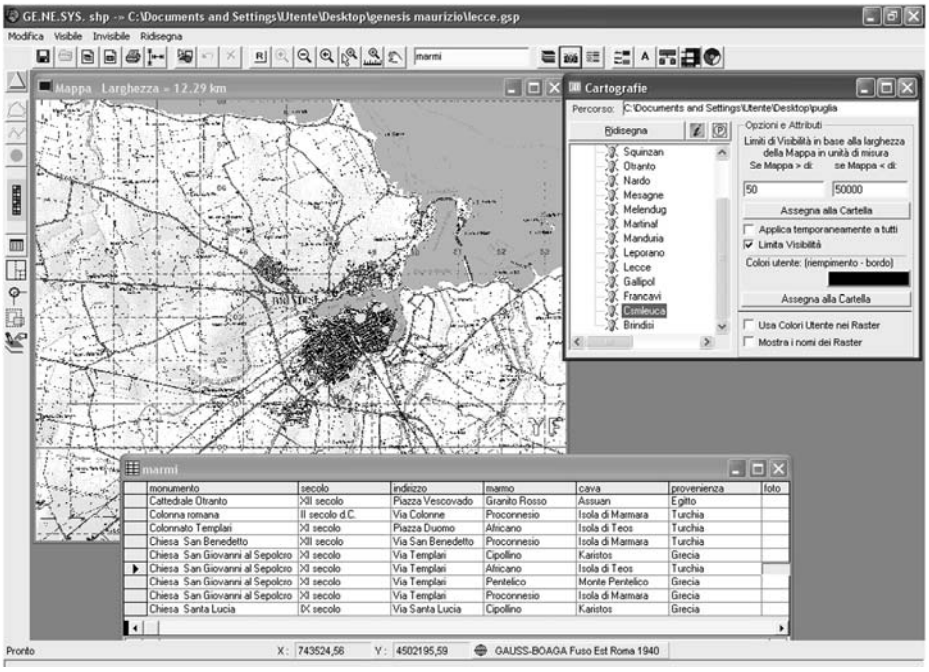
This complex data management, or the procedures to store and to search information that are introduced in a GIS, is committed to a database that manage informative relationships.

The path to locate information is structured in "research-keys", with a univocal target and a differentiated hierarchy too: for example, it will be possible to search for single artistic-architectural emergencies of medieval buildings in Apulia or structural and morphological characteristics of ancient marbles of the analysed emergency. The management of different cartographic themes that are associated to a cultural heritage is based on overlay technique, that is coding base information by different layers.

4 CONCLUSIONS

This tool of analysis that is constantly updated and has reading-understanding agility is composed documents that are useful not only for scientific research, but also for institutional requests, in order to launch local or regional activities to recover, from the building and economic point of view, the historic-architectural heritage of Apulia.

So this study contains hints to give value to suggestions of territorial development for an organic plan for recovering marble heritage, so that it can be useful like redevelop of a large territory.



Percorso: C:\Documents and Settings\Utente\Desktop\puglia

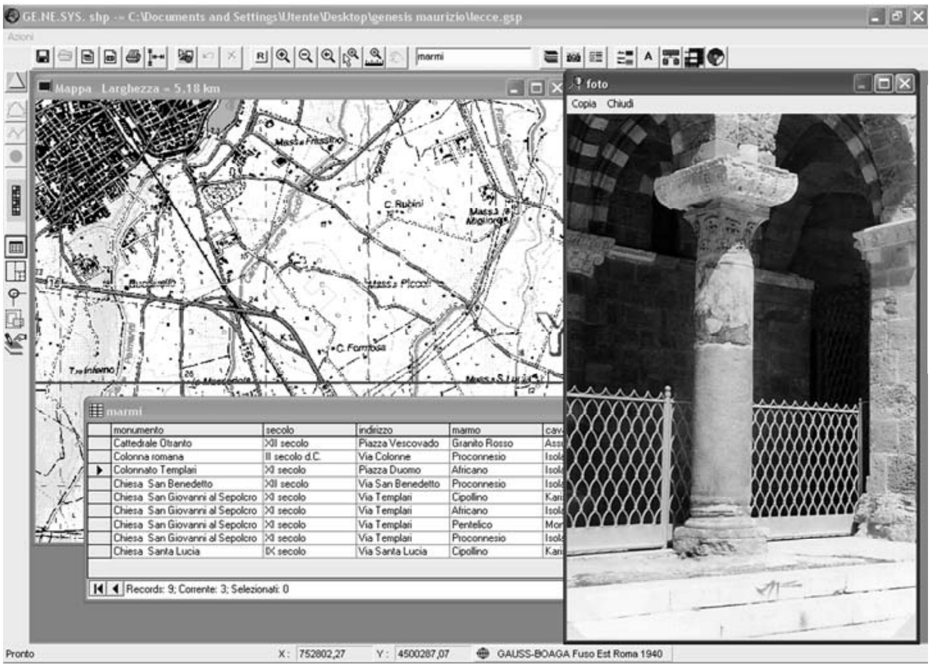
Limiti di Visibilità in base alla larghezza della Mappa in unità di misura
Se Mappa > di: 50
se Mappa < di: 50000

☐ Applica temporaneamente a tutti
☑ Limita Visibilità
Colori utente: (riempimento - bordo)
☐ Usa Colori Utente nei Raster
☐ Mostra i nomi dei Raster

	monumento	secolo	indirizzo	marmo	cava	provenienza	foto
	Cattedrale Otranto	XII secolo	Piazza Vescovado	Granito Rosso	Assuan	Egitto	
	Colonna romana	II secolo d.C.	Via Colonne	Proconnesio	Isola di Marmara	Turchia	
	Colonnato Templari	XI secolo	Piazza Duomo	Africano	Isola di Teos	Turchia	
	Chiesa San Benedetto	XII secolo	Via San Benedetto	Proconnesio	Isola di Marmara	Turchia	
	Chiesa San Giovanni al Sepolcro	XI secolo	Via Templari	Cipollino	Karistos	Grecia	
▶	Chiesa San Giovanni al Sepolcro	XI secolo	Via Templari	Africano	Isola di Teos	Turchia	
	Chiesa San Giovanni al Sepolcro	XI secolo	Via Templari	Pentelico	Monte Pentelico	Grecia	
	Chiesa San Giovanni al Sepolcro	XI secolo	Via Templari	Proconnesio	Isola di Marmara	Grecia	
	Chiesa Santa Lucia	IX secolo	Via Santa Lucia	Cipollino	Karistos	Grecia	

X: 743524,56 Y: 4502195,59

Figure 1 – Screen during a work session.


GE.NE.SYS. shp -» C:\Documents and Settings\Utente\Desktop\genesis maurizio\lecce.gsp
Azioni
marmi
Mappa Larghezza = 5.18 km
foto
Copia Chiudi
marmi
Pronto
GAUSS-BOAGA Fuso Est Roma 1940

	monumento	secolo	indirizzo	marmo	cav
	Cattedrale Otranto	XII secolo	Piazza Vescovado	Granito Rosso	Ass
	Colonna romana	II secolo d.C.	Via Colonne	Proconnesio	Isol
▶	Colonnato Templari	XI secolo	Piazza Duomo	Africano	Isol
	Chiesa San Benedetto	XII secolo	Via San Benedetto	Proconnesio	Isol
	Chiesa San Giovanni al Sepolcro	XI secolo	Via Templari	Cipollino	Kari
	Chiesa San Giovanni al Sepolcro	XI secolo	Via Templari	Africano	Isol
	Chiesa San Giovanni al Sepolcro	XI secolo	Via Templari	Pentelico	Mor
	Chiesa San Giovanni al Sepolcro	XI secolo	Via Templari	Proconnesio	Isol
	Chiesa Santa Lucia	IX secolo	Via Santa Lucia	Cipollino	Kari

Records: 9; Corrente: 3; Selezionati: 0

X: 752802,27 Y: 4500287,07

Figure 2 – Screen during a work session.

5 REFERENCES

Aronoof, S. 1983. *Geographic Information System: Management Perspective,* WDL Pubblications. Ottawa (Canada).

Burrough, P.A. 1986. *Principles of Geographical Information System for Land Resources Assessment* , Clarendon Press. Oxford. U.K.

Pensabene P. 1991. *Contributo per una ricerca sul reimpiego e il "recupero" dell'Antico nel Medioevo. Il reimpiego nell'architettura normanna,* in RINASA, III, Anno III, Roma.

Colesanti, G., Delli Santi, M., Fonseca, C. D., Geraldi, E., Gizzi, F. T., Masini, N., Montesano, N., Potenza, M. R. 2001. *Atella, town of Angevin foundation: cataloguing, managment and improvment of the architectural heritage through a geographical information system.* Proceedings of Workshop Italia-Canada, Organized by Interdepartment research Center of Cartography, Photogrammetry, Remote Sensing and GIS, University of Padua – Agripolis, Padova 3-4 Aprile 2001. CD-ROM.

Colesanti, G., Delli Santi, M., Fonseca, C. D., Geraldi, et al., E., Gizzi, F. T., Masini, N., Montesano, N., Pellettieri, A., Potenza, M. R. 2001. *A GIS for cataloguing, managing and improving the Cultural Heritage in the area of Vulture in Basilicata.* Proceedings of 3rd International Congress on "Science and Technology for the safeguard of Cultural Heritage in the Mediterranean Basin, 9-14 July 2001, Alcalà de Henares SPAIN.

Delli Santi, M.**,** Masini, N., Montesano, N., Pellettieri, A., Potenza, M. R. 2001, *G.I.S. e Beni Culturali: i centri scomparsi nella Basilicata,* in Proceedings of 5° National Conference ASITA: La qualità nell'Informazione Geografica (Palacongressi di Rimini, 9-12 ottobre 2001), vol. II, pp. 701-706.

Using GIS for storing and analysing information concerning the consequences of earthquakes in historical centres

F.T. Gizzi, M.R. Potenza, N. Masini

Istituto pei i Beni Archeologici e Monumentali 85050 Tito Scalo (PZ) Italia- e-mail: f.gizzi@ibam.cnr.it

Keywords: earthquake, historical data, damage pattern, GIS, historical centre

ABSTRACT: The wealth of documents (primary and secondary sources), especially concerning some Italian earthquakes happened in the XIX and XX century, entails the need to have effective tools to store and to manage such data. In this perspective, the work illustrates the use of GIS for managing administrative and technical information associated to earthquakes of the past that affected historical towns. Two towns of Basilicata (southern Italy) and two earthquakes (1857, Io=XI MCS, Me=7.0; 1930, Io=X MCS and Me=6.7) that strongly hit the region are considered here.

In this background, the paper emphasizes two aspects: the use of GIS as a tool both for a crosscheck of information and for setting up strategies for mitigating the seismic risk in historical centres.

1 INTRODUCTION

Macroseismic effects are able to highlight urban areas where anomalously large damage occurred in the past. Indeed to identify more damage areas is the starting point for further analyses aimed at highlighting the causes of ‘anomalies’ in damage distribution. Further research based on data collection and analysis (e.g.: field surveys, boreholes and geophysical prospecting) may be able to determine the impacts of site features on damage distribution (e.g.: Gizzi, 2006). In this way, potentially ‘weak’ urban zones can be identified so that suitable prevention strategies can be implemented.

Therefore, it emerges that collecting and analysing as many documentation as possible is a pressing need to mitigate seismic risk of both single (e.g.: monuments) and stock of buildings (e.g.: quarters of towns).

Starting from these preliminary remarks, the paper deals with the building and the usefulness of GIS for storing and managing descriptive, parametric and iconographic sources concerning seismic damage suffered by private buildings and monuments. Two towns of Basilicata (Southern Italy) and two earthquakes (1857, and 1930) that strongly hit the region are considered here (figure 1).

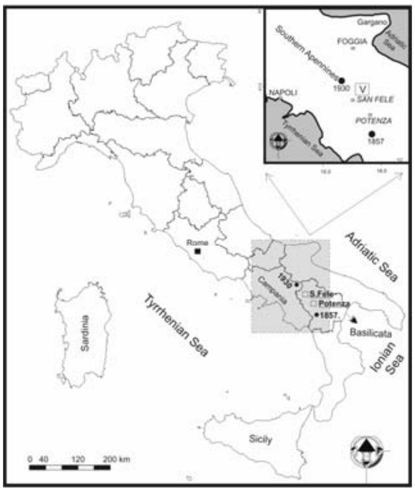


Figure 1/ Sketch map illustrating the study area and the seismic events analysed.

The study area is located on a hill in the southern Apennines where an axial-active, 30 to 50 km wide seismic belt produces strong earthquakes. On the one hand the 1857 event (Io=XI MCS, Me=7.0) caused massive damage in about thirty towns, including Potenza (VIII-IX MCS), the chief-town of Basilicata. On the other hand the 1930 Irpinia quake (Io=X MCS and Me=6.7) killed 1404 people bringing on huge effects in a wide area between Campania and Basilicata.

The use of GIS for analysing data concerning these two events is analysed in the following paragraphs.

2 23 JULY 1930 IRPINIA EARTHQUAKE: DAMAGE IN TOWNS LOCATED AT THE FOOT OR CLOSE TO VOLCANO VULTURE

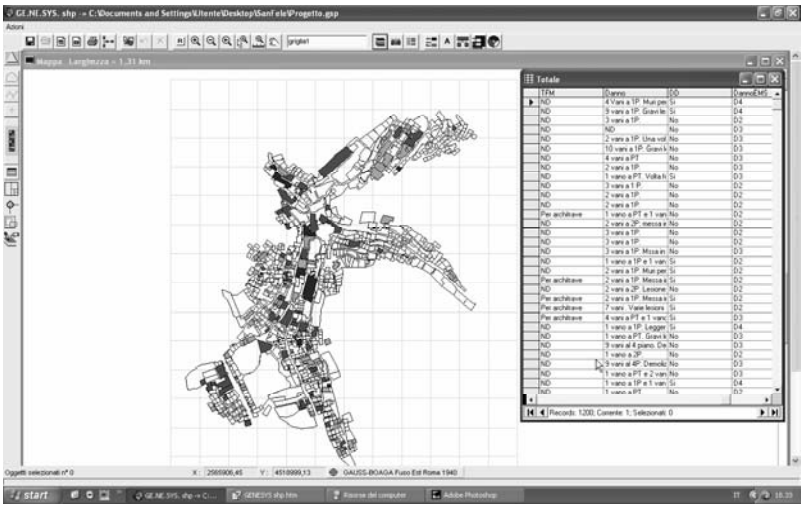
The most affected area was the territory ranging from Melfi to Ariano Irpino, including some towns of Basilicata localised mainly at the foot or close to the extinct volcano Vulture, Pleistocene in age.

Just for these towns is available a rich and unpublished technical and administrative documentation produced aftermath the earthquake by the *Genio Civile* (Civil Engineers).

On the whole, the technical and administrative documents are useful both to analyse the institutional response and to parameterize the damage suffered by buildings. Moreover, the complementary use of technical and administrative data are very useful to evaluate the building damage if direct description of it is not available. Indeed, in this case the damage may be derived from a correlation among restoration works, work times, repair costs, and building size. Obviously, all these data can also be used to check the reliability and the correct interpretation of the semantic value of statements concerning direct damage descriptions.

With this in mind, it was deemed appropriate to use a GIS for storing and managing the wealth of documents available with a final view of obtaining suitable outputs to identify mitigation strategies.

The GIS database, grouped by towns, was associated to each spatial unit (cadastral parcel) identified through historical cartography. Database contains two categories of information, original quotations and data rising from a suitable parameterization and/or elaboration of the quotations themselves.


GE.NE.SYS. shp -> C:\Documents and Settings\Utente\Desktop\SanFele\Progetto.gsp
Azioni
Mappa Larghezza = 1,31 km
Totale
Oggetti selezionati n° 0
X: 2565906,45
Y: 4518999,13
GAUSS-BOAGA Fuso Est Roma 1940
start
Adobe Photoshop

TFM	Danno	DO	DannoEMS
ND	4 Vani a 1P. Muri per	Si	D4
ND	9 vani a 1P. Gravi le	Si	D4
ND	3 vani a 1P.	No	D2
ND	ND	No	D3
ND	2 vani a 1P. Una vol	No	D3
ND	10 vani a 1P. Gravi l	No	D3
ND	4 vani a PT	No	D3
ND	2 vani a 1P.	No	D3
ND	1 vano a PT. Volta l	Si	D3
ND	3 vani a 1 P.	No	D2
ND	2 vani a 1P.	No	D2
ND	2 vani a 1P.	No	D2
Per architrave	1 vano a PT e 1 van	No	D2
ND	2 vani a 2P. messa e	No	D2
ND	3 vani a 1P.	No	D2
ND	3 vani a 1P.	No	D2
ND	3 vani a 1P. Messa in	No	D3
ND	1 vano a 1P e 1 van	Si	D2
ND	2 vani a 1P. Muri per	Si	D2
Per architrave	2 vani a 1P. Messa a	Si	D2
ND	2 vani a 2P. Lesione	No	D2
Per architrave	2 vani a 1P. Messa a	Si	D2
Per architrave	7 vani . Varie lesioni	Si	D2
Per architrave	4 vani a PT e 1 vano	Si	D3
ND	1 vano a 1P. Legger	Si	D4
ND	1 vano a PT. Gravi l	No	D3
ND	9 vani al 4 piano. De	No	D3
ND	1 vano a 2P.	No	D2
ND	9 vani al 4P. Demoliz	No	D3
ND	1 vano a PT e 2 van	No	D3
ND	1 vano a 1P e 1 van	Si	D4
ND	1 vano a PT	No	D2

Records: 1200; Corrente: 1; Selezionati: 0

Figure 2 / Damage map processed using original sources whose quotations were digitalised into a spreadsheet.

Original information consist of cadastral data, repair costs, work time, damage and restoration work descriptions. Each of these subjects was identified as a field in the database.

Once implemented, some of such data were resolved into their elements to identify building techniques (therefore the vulnerability) and the damage to each structural element. This last aspect allowed, for example, to perform an easier classification of the damage. Indeed, once the degree of damage of each structural element was established, the building effects were parameterised according to the five degrees of the EMS-98 scale, which considers the following five damage classes for masonry buildings: slight (D1), moderate (D2), substantial to heavy (D3), very heavy (D4) and destruction (D5). Database was also added of fields automatically built up from original data by “calculated field” function of GIS (e.g.: work time).

For every field, the analysis by GIS allowed to make thematic maps useful to analyse specific aspects. Regarding the 1930 damage ‘scenario’ for San Fele, a town for which remarkable original sources are available, it is possible to observe an articulate picture of damage. Central and northern portions of the town, where damage D3 and D4 is prevalent, are the most affected areas (figure 2).

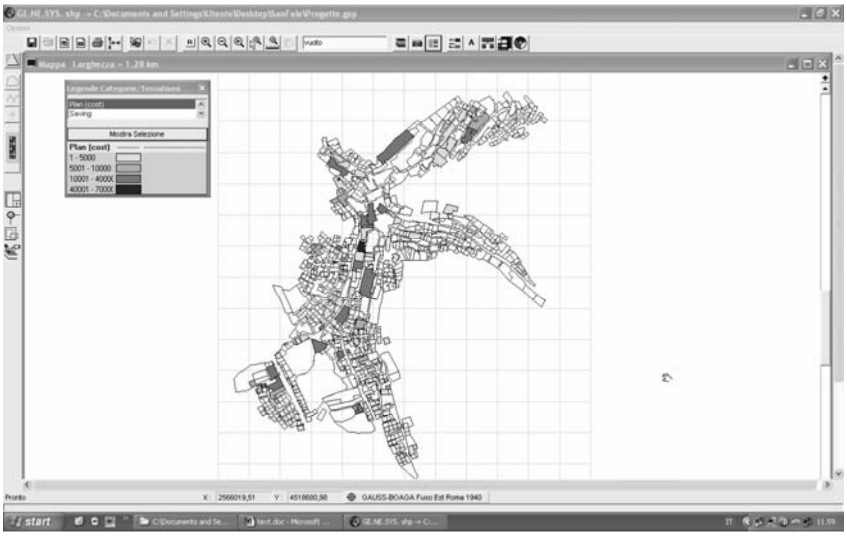
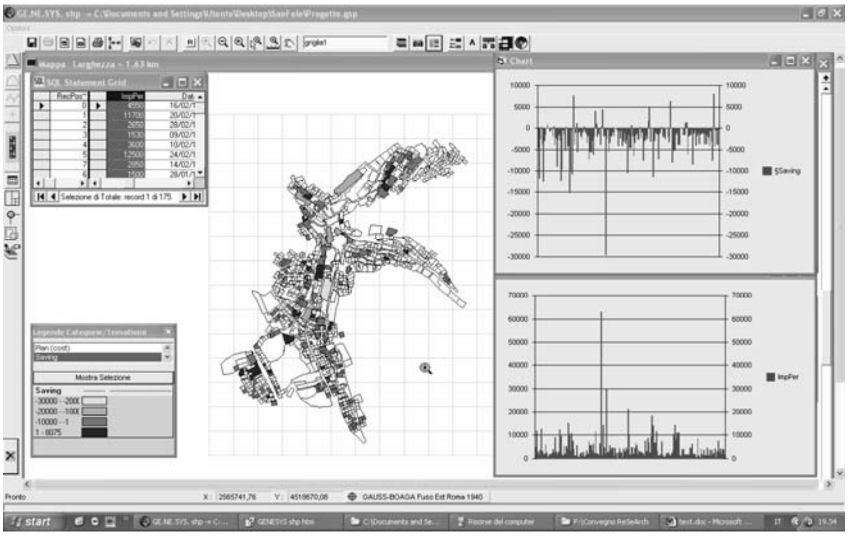

GE.NE.SYS. shp -> C:\Documents and Settings\Utente\Desktop\SanFele\Progetto.gsp
vuoto
Mappa Larghezza = 1,28 km
Legende Categorie/Tematismi
Plan (cost)
Saving
Mostra Selezione
Plan (cost)
1 - 5000
5001 - 10000
10001 - 4000(
40001 - 7000(
Pronto
X: 2566019,51 Y: 4518680,98
GAUSS-BOAGA Fuso Est Roma 1940
start

Figure 3 / Pattern of costs expected for the rebuilding


GE.NE.SYS. shp -> C:\Documents and Settings\Utente\Desktop\SanFele\Progetto.gsp
griglia1
Mappa Larghezza = 1,63 km
SQL Statement Grid
Chart
$Saving
ImpPer
Legende Categorie/Tematismi
Plan (cost)
Saving
Mostra Selezione
Saving
-30000 - -200(
-20000 - -100(
-10000 - -1
1 - 8075
Pronto
X: 2565741,76 Y: 4519670,08
GAUSS-BOAGA Fuso Est Roma 1940
start

RecPos	ImpPer	Dat
0	4550	16/02/1
1	11700	20/02/1
2	2650	28/02/1
3	1530	09/02/1
4	3600	10/02/1
5	12500	24/02/1
7	2950	14/02/1
6	1500	28/01/1

Selezione di Totale: record 1 di 175

Figure 4 / Savings followed to the final accounting of the works. Graphs show the savings (top, reduction of costs is evident) and expected rebuilding costs (bottom, the most of values suggest low damage)

The reliability of these damage data is strengthened comparing them with the map showing the costs expected for the rebuilding. Indeed, this map indicates that higher rebuilding costs are prevalent in the areas where higher damage occurred (figure 3). A further validation of damage data may be found in the savings followed to the final accounting of the works. This thematic cartography shows that savings were higher in the southern portion where a lower effects were recorded, whereas to the north of the town savings were lower or even an increase of costs was sustained by owners (figure 4).

The enrichment of the database with geological features of the site is in progress. This allowed to select the possible causes of the severest damage.

3 16 DECEMBER 1857 BASILICATA EARTHQUAKE: DAMAGE IN POTENZA

Potenza is a town that in historical times was affected by at least eight earthquakes with intensities higher than or equal to VI MCS, including 1857 event (Is= VIII–IX MCS). This quake represents the most damaging historical earthquakes for which it was possible to map the affected buildings, owing to the good quality of the retrieved information. Therefore, all available information was implemented to make up the basis of the GIS. The building was performed in two main phases.

In the first one, the GIS was built in damage-analysis perspective and, therefore, were acquired data such as descriptive technical documentation (mainly of archival feature), iconographic sources, and historical cadastral map, dating back to 1875. Descriptive information arises from resolutions of central and local commission that were established immediately after the event with the tasks supervising the rebuilding of damaged houses by distributing money to the owners of those houses and surveying the damaged buildings as well, to decide whether or not to demolish severely damaged houses. The descriptive effects were converted into parametric data according to the EMS-98 scale. Each descriptive and parametric information was identified as a field and digitalised into a spreadsheet. Once ended the digitalisation, by using the data analysis tools, some appropriate thematic maps were obtained.

As regards the second phase, to identify the causes of highest damage, geological (field survey, drillings, stratigraphic sections), geotechnical (laboratory and site analysis), and geophysical data (down-holes and seismic refraction measurements) were implemented in a geodatabase on a GIS platform. By spatial analysis function was obtained detailed information about subsurface geology.

The overlay between damage and site geology suggests that stratigraphic and dynamic properties of the soils can partially explain the occurrence of the heaviest effects in the western portion of the town (figures 5 and 6). Indeed, site features are responsible of differential amplification phenomena (Dolce *et al.*, 2001)

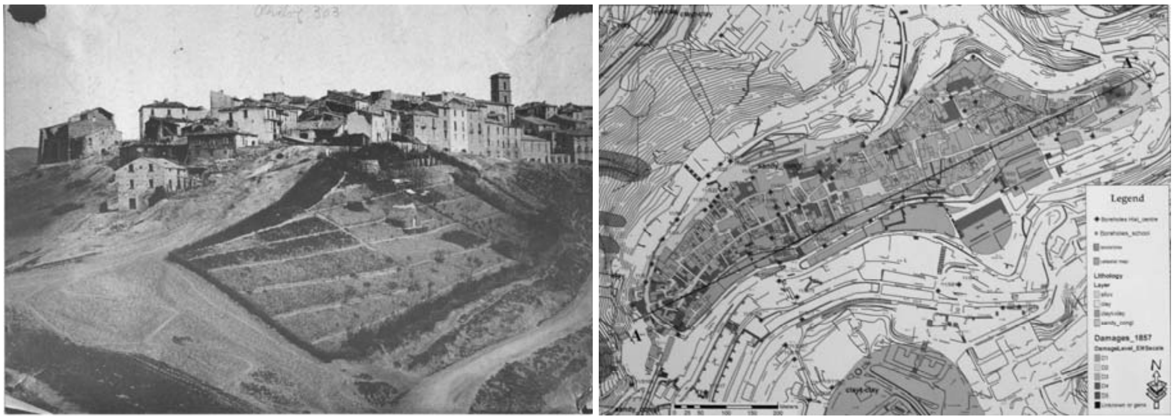


Figure 5 and 6 / Damage in western part of Potenza downtown (left, from Mallet, 1862); overlay between damage pattern and geological features of Potenza (right, after Gizzi et al.,2007)

4 CONCLUSION

This paper dealt with the role of GIS for analysing technical and administrative information concerning historical earthquakes. Explaining how the GIS can be helpful in this perspective, two case studies have been considered here.

Starting from the role of GIS as a tool to analyse and to check the reliability and the correct interpretation of statements by a cross-correlated interpretation of some pieces of information (1930 event), it has been shortly paid light on the utility of GIS overlay tool to infer the geological features causing the clustering of the damage (1857 event).

Summarizing, the capacity of GIS to store a great amount of information is of great help for processing data related to earthquakes, also considering that the chance of updating the database with new studies on historical or present-day earthquake effects will contribute to step up the surveys on damage anomalies and, therefore, to better identify the area/s repeatedly affected by severest seismic actions. New geological data on these areas allowed to disclose the more convincing cause/s of the uneven effects and, therefore, to fix up the suitable mitigation actions for monuments and/or earthquake-prone historical centres.

5 REFERENCES

Dolce, M., Masi, A., Marino, M., Vona, M. 2001. Uno scenario di danno sismico per la città di Potenza, X Convegno nazionale L'Ingegneria Sismica in Italia, Potenza, Italia, 9-13 settembre 2001.

Gizzi, F.T. 2006. To what degree can historical seismicity records assist in seismic microzonation? Engineering Geology 87: 1-12.

Gizzi, F.T., Lazzari, M., Masini, N., Zotta, C. 2007. Geological-geophysical and historical-macroseismic data implemented in a geodatabase: a GIS integrated approach for seismic microzonation. Poster Presentation at EGU, General Assembly, Vienna, Austria, 15-20 April 2007. Geophysical Research Abstracts, 9, 09522.

Mallet, R. 1862. The Great Neapolitan Earthquake of 1857. 2 voll. London, October 1862, reprinted by Istituto Nazionale di Geofisica. Roma, 1987.

Basic Statistic Measures for IRT images analysis: a ‘sample wall’ taken from Matera Cathedral

M. Danese, D. Sanseverino

C.N.R. – I.B.A.M. C/da S. Loja Zona Industriale Tito Scalo (PZ) 85050, Italy, E-mail: m.danese@ibam.cnr.it: d.sanseverino@ibam.cnr.it

Keywords: GIS, Raster classification, non-destructive testing of material decay, multi-temporal infrared thermography, cultural heritage.

ABSTRACT.
The aim of this work is to explore a multitemporal infrared thermographic dataset by means of a classification procedure based on statistic measures in order to find spatio-temporal clusters.
This procedure has been applied on a sample wall of the Matera Cathedral.
The found spatio-temporal clusters allowed to extract a characteristic pattern that helped us to understand the level and the kind of decay of the sample wall.

1 INTRODUCTION

The Infrared Thermography (IRT) was born in the first years of the last century for military reasons but now it’s becoming important in very different application fields, because of the potentialities that it shows also in different research areas. The aim of this work is to use multitemporal IRT (MIRT) for cultural heritage preservation, to improve the quality of the informations that we want to have about the constructive elements surface and to understand their conservation conditions.

According to Avdelidis & Moropoulou (2004), the process of the heat transfer depends from the spectral, thermal and geometrical properties of a material. So we can suppose that a material with equal conditions of decay has a univocal behaviour and that, even if a wall is perhaps an improper geographical element, it is very important to consider how temperature varies in the space, that is along the wall, as well as in time. From this consideration it is possible to understand how important is the research of spatio-temporal clusters to study in situ materials the conditions of decay in a non-destructive way.

To look for these patterns we used a simple approach, in a GIS environment, based on the classification and the studies of IRT multitemporal (MIRT) images with statistic measures, in order to help the visual qualitative exploration and research of significative clusters and to quantify, in a fast way all the features and the phenomenologies that is possible to find on face walls. We are interested to these patterns because they’re symptomatic of the decay of the wall that should be preserved during the time.

2 A MULTITEMPORAL IR THERMOGRAPHIC DATASET TAKEN FROM MATERA CATHEDRAL AND THE GIS ENVIRONMENT

A MIRT survey in situ was done on a sample wall taken on the west façade of Matera Cathedral (figure 1, left 1), a remarkable church of the Romanesque style in Southern Italy, located on a panoramic spur facing the famous ancient town “The Sassi” of Matera, included in the World Heritage List.

The basic dataset is made of thermographic images taken every 30 minutes, in a monitoring carried out from 21:00 to 00:00 of the 19th July 2008.

The dimensions of the analysed sample wall are 128 x 96cm. The wall is composed of a masonry structure with squared ashlars in quartzitic calcarenite that are 25cm high and a width between 18-48cm, placed in horizontal courses and staggered, joined with 0,5cm of cement mortar.

This sample was selected because it is representative of the materials and the decay pathologies which typically characterize the historical built heritage in Matera.

As regards the decay, the figure 1 (right) puts in evidence the categories (figure 1, right):

1) two different levels of alveolization, among which one is characterised by isolated alveoli, the other one by alveoli bint, that have the typical serpentine shape;

2) erosion that, for calcarenite, in an advanced phase, becomes alveolization;

3) deposits with brownish colour, which in particular affect the first ashlar on the top left. This probably is due to a superficial treatment made to the stone in the past years.

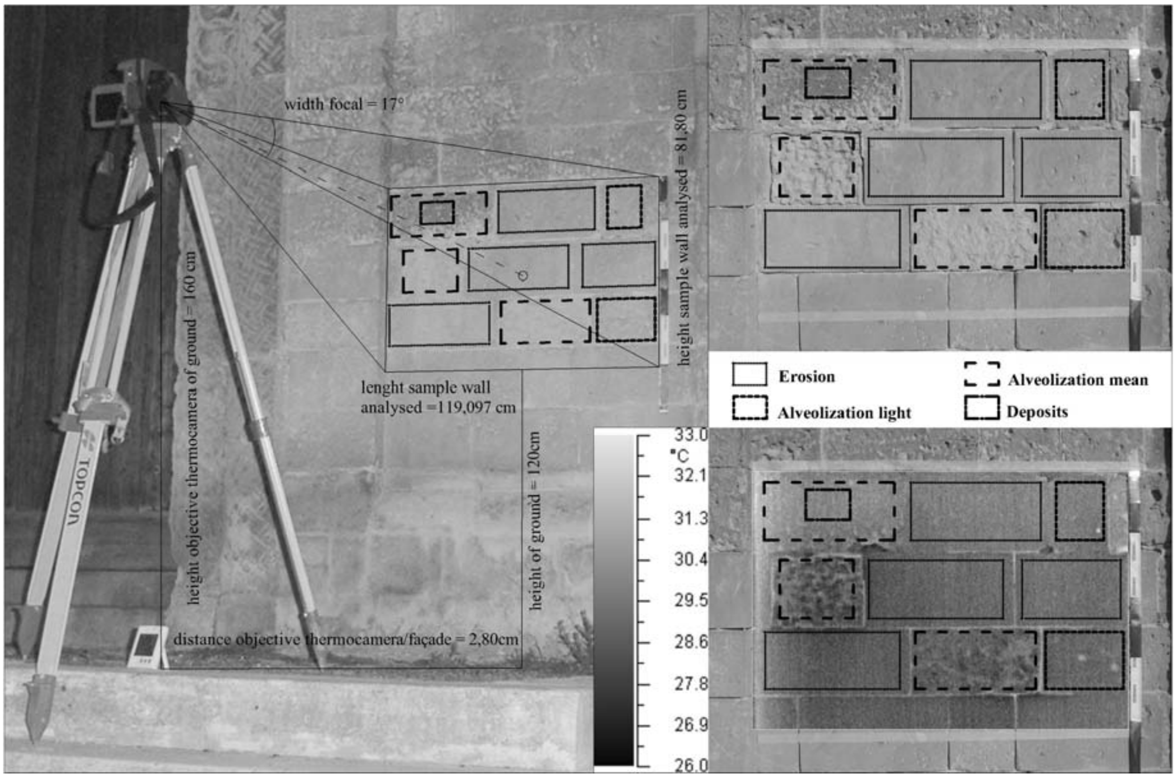

width focal = 17°
height sample wall analysed = 81,80 cm
lenght sample wall analysed =119,097 cm
height objective thermocamera of ground = 160 cm
height of ground = 120cm
distance objective thermocamera/façade = 2,80cm
TOPCON
Erosion
Alveolization mean
Alveolization light
Deposits
33.0
°C
32.1
31.3
30.4
29.5
28.6
27.8
26.9
26.0

Figure 1. (left) Relief scheme and the sample wall analysed; (right)verlay between the different types and levels of superficial decay of the stones and one of the thermographical image of the sample wall analysed.

The bearing was done in the evening, during the cooling and the heat letting from the façade, after the direct irradiation occurred from the first hours in the afternoon, in a warm july day (mean temperature 30°C, mean relative humidity 40%, absence of ventilation). We selected the evening hours to minimize the phenomenon of selective absorption of the solar radiation from the stones that have different superficial colours (like for example the ashlar with crust).

The measured environmental temperature was from 26,9°C at 21:00 to 24,9°C at 22:30; these value was constant until midnight; the total thermical gradient is 2,0°C. At the same time there was a decreasing external humidity, equal to 1%from 21:00 (at 22:30) to 49-52% (from 23:00 to 24:00).

The thermocamera used was AVIO TVS 600 microbolometric that works in “long wave” spectral band between 8-14 micron, with lens of 35 mm, four temperature sensors and the pixel dimension equal to 4,01 mm in a target range of 2,80 m, measured from the focus to the wall. Pixel temperatures were calculated considering for calcarenite the emissivity $\varepsilon = 0{,}67$ (Omega Engineering Inc., 1998).

The first kind of classification (figure 2, column 1) of the dataset is based on an absolute reading scale, built a-priori, defining an interval of 1 Celsius degree.

From the picture we can see how temperature decreases along the wall, but it’s difficult to understand which are the parts that keep heat for longer time and which ones become cold faster.

For this reason we did a second kind of classification (figure 2. column 2). It is instead based on a relative reading scale, where defined intervals represent quantiles, also represented in the frequency diagrams (figure 3, column 3), where there are reported also other important statistical characteristics of the distribution. In this way, for example, it is possible to emphasize pixels that in each photograms are the maximum and the minimum extremes of the temperature distribution and that have a respective similar behaviour. In this way it is possible to find two decay pattern: one is characterised from higher temperature, that means humidity, or eventually, the presence of incoming chemical reactions, the other one is characterised by lower temperature, that is alveoli that have more heat exchange with the environment, so the ashlars with them become cold faster.

For what concern the crust it is not possible to determine a univoque pattern, because in that area there are simultaneously different classes of temperature values and frequencies.

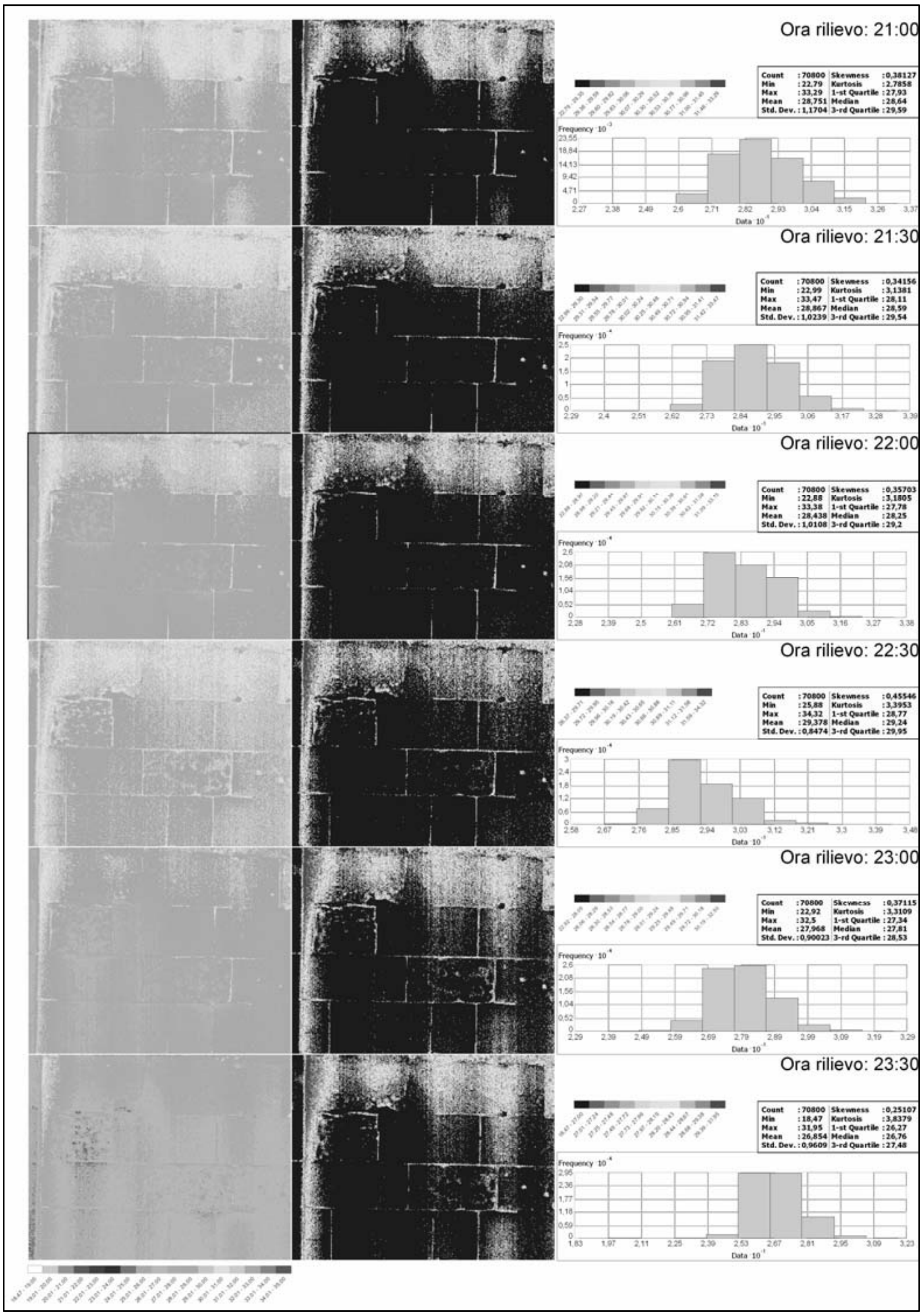


Figure 2. Classification of their IR thermographical dataset: (column 1) with an absolute scale; (column 2) with a relative scale based on frequencies (column 3).

3 CONCLUSION

The paper showed the results of an exploration of a multitemporal infrared thermographic dataset performed on a sample wall of the Matera Cathedral.

The procedure based on statistic measures allowed us to extract spatio-temporal clusters which provided useful information on the level and the kind of decay of the sample wall.

This work proved the capability of an approach based on the processing of statistic measures a multitemporal infrared thermographic dataset for the study of conservation of historical buildings and artifacts.

In the future, it is desirable to improve the methodology by using data mining techniques in order to have a robust scientific instrument capable to support the reading of the great number of information contained in a multitemporal IR thermographical dataset and to make the extraction of significant categories for the decay.

4 REFERENCES

Avdelidis, N. P., Moropoulou, A. 2004. Applications of infrared thermography for the investigation of historic structures. *Journal of Cultural Heritage*, 5: 119-127.

Avdelidis N.P., Moropoulou A. 2003. Emissivity considerations in building thermography. *Energy and Buildings*.35: 663–667.

Bison P.G., Grinzato E., Marinetti S. 2003. Monitoring of ancient buildings by the thermal method. *Journal of Cultural Heritage*, 3: 21-29.

Brink A., Maierhofer C, Röllig M., Wiggenhauser H. 2005. Quantitative impulse-thermography as non-destructive testing method in civil engineering. Experimental results and numerical simulations. *Construction and Building Materials*, 19:731-737.

Carlomagno G.M., Di Maio R., Meola C., Roberti N. 2005. Application of infrared thermography and geophysical methods for defect detection in architectural structures. *Engineerig Failure Analysis*, 12:875-892.

Geraldi E., Gizzi F.T., Masini N. 2003. Termografia all'infrarosso ed archeologia dell'architettura: alcuni esempi. Atti del 22° Convegno del Gruppo Nazionale di Geofisica delle Terra solida. Sessione geofisica applicata ai Beni Culturali, Roma, 18-20 novembre 2003.

Ludwig N. , Milazzo M. 1998. La termografia nella diagnostica delle strutture architettoniche. Atti Castra ipsa possunt et debent reparari. CNR, Castello di Lagopesole, ottobre 1997.

Rosina E. 2004. La percezione oltre l'apparenza: l'architettura all'infrarosso, Firenze.

Ludwig N., Teruzzi P. 2002. Heat losses and 3D diffusion phenomena for defect sizing procedures in video pulse thermography. *Infrared Physics & Technology*.

Omega Engineering Inc. 1998. Transactions in Measurement and Control, vol. 1, Non-contact temperature Measurement, Omega Press LLC. Scaricabile da:

http:// www.omega.com/literature/transactions/volume1/emissivity.html.

8

Landscape archaeology and palaeo-environmental studies based on Remote sensing, GIS and ICT

Three-Dimensional Reconstruction of Prehistoric Landscapes for Multitemporal Static and Dynamic Geovisualization of the Goseck Ring Ditch

T. Richter, D. Thürkow, S. Scheuer, C. Gläßer

Martin Luther University Halle-Wittenberg, Institute of Geosciences, D-06120 - Halle/Saale, Germany. E-MAIL: cornelia.glaesser@geo.uni-halle.de, tobias.richter@gmx.de

Keywords: Multitemporal, 3D Landscape, Visualization, Reconstruction, Prehistoric

ABSTRACT

During the last decades, interest in archaeology shifted remarkably from the more traditional settlement archaeology to the field of landscape archaeology, which focuses on the interactions between mankind and the environment. It therefore concentrates on the relation between human culture and nature, the latter being increasingly affected by human impact. Thus, time and space play a key role in landscape archaeology. Suggestions for standards are proposed in the presented three-dimensional landscape visualization of the ring ditch in Goseck (Saxony-Anhalt, Germany), which is shown in various time segments from the Stone Age to the Present. The work emphasizes the reconstruction of the Goseck ring ditch, the generation of photo-realistic vegetation structures and the three-dimensional reproduction of the different culture's housing types. Furthermore, it is tried to deduce rules which aim to ease the interpretation and habitat analysis of perished cultures and to create a methodology and uniform standards, which make it easier for the intended users to interpret and analyse the habitat of former cultures.

1 INTRODUCTION

The development of new hard- and software in the last years induced a paradigm change in all kinds of data processing. Interactive, photo-realistic 3D and 4D visualization tools and techniques open new applications in geosciences and archaeology. These methods cause a drastic change in the work flow to create landscape reconstructions. This however does not mean that landscape visualizations are also more exacting. It is in fact necessary to develop new standards or enhance existing methods to make use of the new technological possibilities in landscape visualizations. Thus, the increasing computer potential will help to compensate existing methodological deficits. By this, e.g. an increasing photorealism, more real time models, more libraries of readymade elements, more variety in public participation, a better presentation of temporal dynamics and a more powerful connection and interaction with science can be expected (Ervin 2003; Mach 2007).

2 RESEARCH AREA

The Goseck ring ditch is located in the south of Saxony-Anhalt in Germany and was built by the Stroke-Ornamented Pottery culture 7000 years ago. It was detected by a photo flight campaign in 1991. Approximately 2000 tree trunks were used for its construction. The ring ditch was used as a calendar to fix important dates of the year like summer and winter solstice. Exactly at midwinter for example, the sun rises in the south-eastern gate and sets in the south-western gate. That allows the people to set the time for special feasts and rites as well as for agriculture (Meller, 2003; Northe *et al.*, 2006; Bertemes *et al.*, 2007). This amazing monument gives an absolutely new impression of the level of knowledge of our ancestors.

3 METHODS

Uniform standards are proposed in the presented three-dimensional landscape visualization of the ring ditch in Goseck, which is shown in various time periods starting in the Stone Age and ranging to the Present. It was necessary to develop principles for the usage of DTM, 3D-objects, textures, illumination and post-processing and the deduction of a methodology (figure 1). The work emphasizes the reconstruction of the Goseck ring ditch, the generation of photo-realistic vegetation structures and the three-dimensional reproduction of the different culture's housing types. Additionally, rules were deduced which aim to ease the interpretation and habitat analysis of perished cultures. In doing so, this work focuses on the principles for a better and more demanding landscape visualization proposed by Sheppard (2001): representative character, accuracy, optical clarity, interest, legitimacy, internet suitability and fascination.

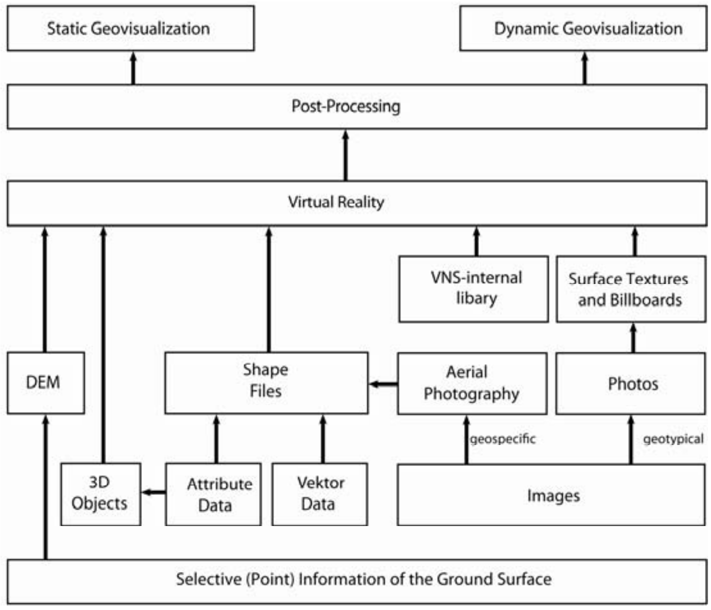


Figure 1. Flowchart of the developed methodology used for the 3D reconstruction of the Goseck ring ditch

All results of static and dynamic visualization were created with the software Visual Nature Studio (VNS), textures and billboards were created with Photoshop, 3D objects with Cinema 4D and all vector data for shape-files with ArcGIS.

4 ELEMENTS OF LANDSCAPE VISUALIZATION

Digital Terrain Model: Primary dataset for the landscape reconstruction is the Digital Terrain Model (DTM) derived from high resolution laser scanner data. The representation of a landscape using a DTM significantly depends on the level of detail of the depicted surface features. A 3D scene is then completed by overlaying the DTM with additional vector data, images and 3D objects. A computer generated landscape is a preliminary result. It can be transform into different final products later on, depending on the post-processing.

Billboards: To increase the realism of landscape visualizations it is important to use region-specific vegetation. To achieve this, accurate research is needed. This becomes especially important in visualizations of former times. The first step involves finding plants which are suitable to typify reconstructed landscapes. Secondly, photos of these plants are taken. It is advisable that the photographed object differs significantly from the background. This will help masking the object in image processing software. After masking, it is exported as a semitransparent texture (billboard) to be used in geovisualization software.

Surface Textures: Surface Textures are used to visualize properties of the ground, i.e. soil texture and vegetation. Photos were taken of various soils. Alterations of the texture for added realism are realized by applying fractal noise. Vegetation is depicted by various billboards. The use of all three components results in a Surface Texture with high realism.

3D Objects: By using a multitude of 3D Objects it is possible to reconstruct complex settlement structures. In the course of this work many different 3D Objects were created to depict changes in landscape and human activity. As an example, different prehistoric culture’s housing types were created with their different parts (wooden skeleton; walls; roof) and their corresponding textures as well as tree trunks, people, animals etc.

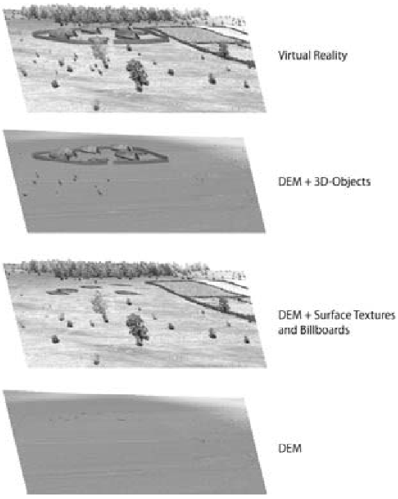
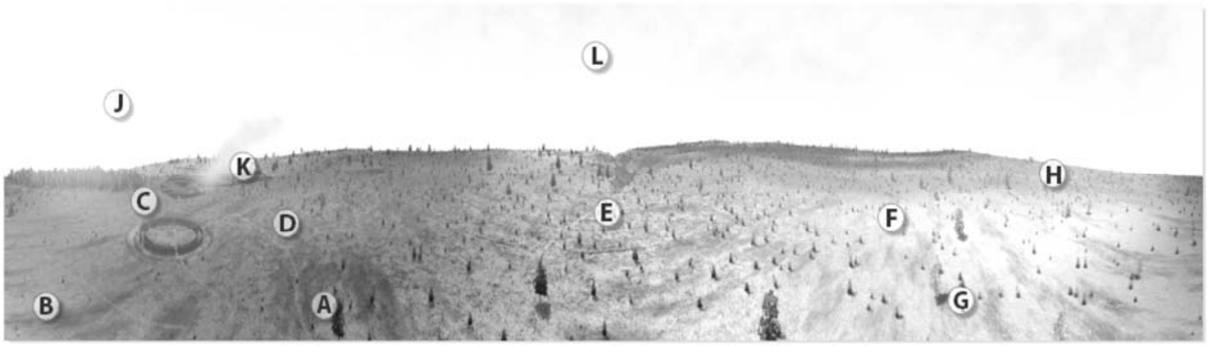


Figure 2. Elements of landscape visualization

5 RESULTS

To illustrate the complex elements used for landscape reconstructions, images and 360° panoramas (static or dynamic geovisualizations, compare also figure 3) as well as fly-over animations (dynamic geovisualizations) for selected times were produced.



igure 3. 360° panorama of the Goseck ring ditch and its vicinity at the time of the Stroke-Ornamented Pottery

Figure 4 shows the different **elements of landscape visualization**, i.e. Billboards (**A**), Surface Textures (**B**) and 3D Objects (**C**), the **different illumination effects** as a function of the sun's altitude and the topography (**D** – Frontlight; **E** – Backlight; **F** - Oblique Illumination; **G** - Rendered Shadows) and all **post-processing steps** (**H** – Haze; **J** – Sun; **K** - Fire and Smoke; **L** - Clouds). By such visualizations, a fantastic and unique trip into the past is possible.

To show landscape changes and changes in the structures of prehistoric settlements, 3D reconstructions have been created, ranging from the Stone Age to the Present (see figure 4).

The developed visualizations are intended to be used by both scientists and the public to (digitally) explore this prehistoric site, e.g. in museums, via the internet, or on the ground of the archaeological heritage itself.

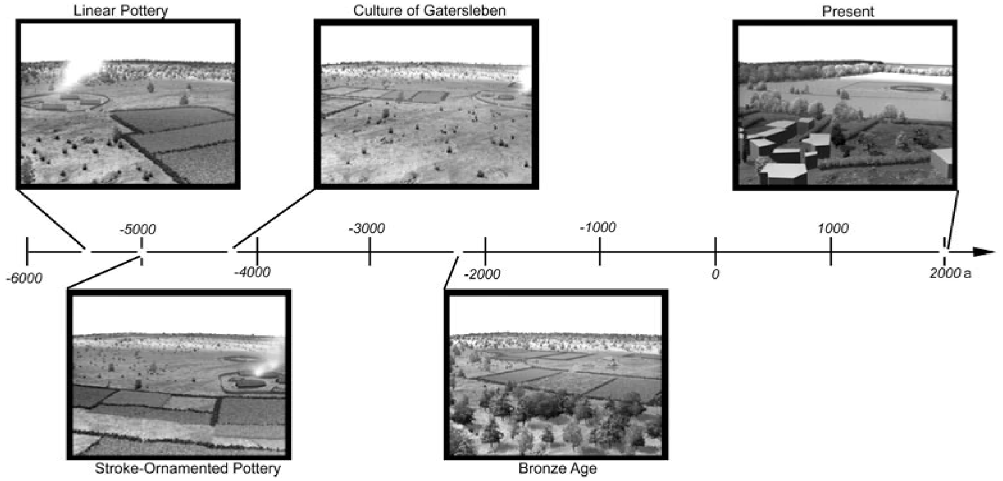


Figure 4. Multitemporal 3D reconstruction for selected times

6 CONCLUSION

The primary aim of this work was the formulation of methods and uniform standards for 3D landscape visualization to compensate existing methodological deficits.

The presentation of temporal conditions and processes using Geographic Information Systems (GIS) and visualization tools can help to answer archaeological questions. The usage of this combination of visualization methods is still in an early development stage though. It can be expected that GIS and visualization tools will increasingly be adopted in archaeology in the future. Hence, the developed visualization and landscape reconstruction methods should be integrated into the workflow employed within archaeological projects to communicate research results more effectively. By this, the public interest in archaeology shall be raised.

7 ACKNOWLEDGEMENT

The authors are very grateful to the Landesamt für Archäologie und Denkmalpflege Sachsen–Anhalt for the supply of the DTM and for the fruitful discussions with Andreas Northe, Institute of Prehistoric Archeology, University of Halle.

8 REFERENCES

Bertemes, F., Northe, A. 2007. Der Kreisgraben von Goseck – Ein Beitrag zum Verständnis früherer monumentaler Kulturbauten Mitteleuropas. In *Vorträge des 25. Niederbayerischen Archäologentag.* Rahden/Westf., Verlag Marie Leidorf, 137-168.

Ervin, S. 2003. Trends in Landscape Modelling. In Buhmann, E., Ervin, S., *Trends in landscape Modeling. Proceedings at Anhalt University of Applied Sciences 2003*, Heidelberg, Wichmann Verlag, 2-8.

Mach, R. (2007). *Visualization of digital terrain and landscape data. A manual.* Berlin, Springer Verlag.

Meller (Ed.) 2003. *Zwölf Jahre Luftbildarchäologie in Sachsen-Anhalt – Pilotstudien.* Halle.

Northe, A., Bertemes, F. 2006. Neolithisches Heiligtum in prähistorischer Kulturlandschaft – die Abschlussuntersuchungen in der Kreisgrabenanlage von Goseck und weitere Grabungen in deren Umgebung. In *Archäologie in Sachsen-Anhalt*, 4, 269-281.

Sheppard, S. R. J. 2007. Guidance for crystal ball gazers: Developing a code of ethics for landscape visualization. In *landscape and urban planning*, 54: 183-199.

Space-borne archaeology: reconstructing ancient landscapes and detecting subterranean construction features in Southern Dobrogea (Romania)

I. A Oltean[1], L. L. Abell[2]

1 Department of Archaeology, University of Exeter, Exeter, EX4 4QE, UK. E-mail: i.a.oltean@exeter.ac.uk
2 Remote Sensing Center, Naval Postgraduate School, Naval Postgraduate School, Monterey, Ca 93943 USA. E-mail: llabell@nps.edu

Keywords: landscape archaeology; aerial reconnaissance; satellite imagery; cropmarks.

ABSTRACT: Traditionally, archaeological aerial surveyors fly routes selected on the probability of site visibility and record only what they perceive as significant. This approach to aerial reconnaissance has come under criticism in recent years with respect to productivity, bias and cost. Through panchromatic imagery with sub-metre resolution and high-resolution multispectral products, modern commercial satellites are capable of recording fine details of both extant sites and archaeological cropmarks. They are not limited by fuel costs, airspace laws, pilot time or conflicting regions of interest. Additionally, the multiple wavelength images and powerful image analysis software available offer the facility to manipulate images to maximise the visibility of surface details as well as to detect distinctions in the non-visible spectrum. This paper discusses the potential of satellite imagery to reveal buried archaeological features in the area of southern Dobrogea (Romania) and assist in the reconstruction of past landscapes through a comparison with data recovered on various dates and with various other methods of acquisition (Quickbird and Corona satellite imagery; WWII vertical aerial photography and recent oblique aerial photographs). It will outline some of the methodological approaches employed, discuss some of the problems needing further research effort and present some preliminary outcomes.

1. INTRODUCTION:

Throughout much of the 20th century aerial archaeology has greatly enriched our knowledge of past human activity, as sites and landscapes across Europe and beyond have been revealed from the air. In countries such as Britain where, since its implementation over 60 years ago, sites discovered through aerial photographic reconnaissance increased the number of sites currently known tenfold. Some of the sites visible from the air are extant, but the success of this methodology is evident particularly in those areas were archaeological features are buried under modern cultivation and revealed by variations in crop development producing recognizable patterns of differential growth, reflecting variations in the availability of soil moisture and nutrients, known as cropmarks. Considerable sums are invested every year in aerial reconnaissance, which utilises light aircraft to take oblique photographs of known or newly identified archaeological sites (in the United Kingdom some 450 hours of flying *per annum*, at a cost in aircraft hire alone of £87,500 - British Academy 2001, 13). But such situation is not comfortably paralleled elsewhere. By 2000, in most European countries some archaeological aerial reconnaissance was taking place annually with significant variations in the extent, funds and usage (e.g. academic research, heritage protection and management), though none comparable to Britain (Bewley & Raczkowski, 2001). But, there are still European countries where, for legal or other reasons, no such archaeological aerial reconnaissance is being undertaken (most notably Greece, Bulgaria and Turkey). In countries like Romania where aerial reconnaissance was similarly discouraged, for a decade since 1998 (when the University of Glasgow began conducting aerial photographic research projects covering limited geographical areas) aerial reconnaissance has remained confined to the limited resources offered by bodies funding academic research. Furthermore, despite its importance for the understanding and management of archaeological landscapes, few countries mentioned such usage, with only England having a coherent national programme of mapping in place (British Academy, 2001, 16).

The advantages of traditional aerial reconnaissance methodologies include: enhanced ground resolution, the opportunity to photograph sites from various angles and data acquisition at the best possible time in crop development to reveal cropmarks. But, as cropmark formation is heavily dependent on climatic conditions, cultivation patterns and soil types, most reconnaissance flights are seasonally restricted and tend to focus on areas most likely to produce good results. Large areas are then omitted because of their potentially less favourable conditions for data recording, thus generating an inbuilt bias in data recovery (Hanson, 2005). Therefore, the serendipitous and subjective coverage of wider landscapes has been criticised more recently as not being the most productive and cost-effective method (e.g. Palmer, 2005). Arguments in favour of block vertical aerial photographic coverage, normally used for the purposes of photogrammetry, are dismissed by most aerial archaeology practitioners as impractical, with an unproven or poor cost-benefit ratio. The debate, however, has largely overlooked the significant potential contribution of satellite imagery. Image data is becoming increasingly easy to obtain and process with current digital technology and is already showing a cost reduction trend, indicating increased ease of purchase over time. But data processing by means of mathematical algorithms and statistical analyses (part of automated pattern detection, a technology still very much in progress) do not always allow confident interpretation of archaeological features and the visual recognition of potentially significant patterns and employing photographic interpretation methods may allow for more detailed site plan reconstruction (Lasaponara & Masini, 2006; Lasaponara & Masini 2007; De Laet *et al.*, 2007). For the detection of buried archaeological remains the traditional advantages associated with aerial data collection listed above are increasingly becoming less unique, with only the ground resolution remaining superior. With the improvement of current commercial satellite imagery, ground resolution at 0.6 m, off-nadir view options, and increasingly available time continuous global site tasking, the unique advantages that satellite data offer greatly improve the cost-benefit.

2. THE STUDY AREA:

The sites discussed in this paper are located in Southern Dobrogea (Romania) not far from the western coast of the Black Sea and the Bulgarian border. Site A (UTM-WGS84 35N 625000E / 853400N) is positioned immediately to the west of the modern town Mangalia; sites B and C (UTM-WGS84 35N 622247-623561E / 4848137N) are in the middle of the cultivated plateau to the south of Mangalia, some distance from all the villages in the area (Hagieni, Limanu and Vama Veche). The conditions for the formation of cropmarks are very favourable. Dobrogea is Romania's warmest and driest region, with predominantly intense and short-lived rainfall, much of it in the spring, and occasional hot dry winds emanating form the Russian steppe. Furthermore, the geology allows rapid drainage of moisture. The soil from both areas is levigated chernozem. Site A may benefit from more humidity, through the presence of clays in combination with limestones and sands along with the nearby silted up estuary, than sites B and C located on loess at some distance from the Black Sea or any other sources of water (Oltean & Hanson, 2007a). Given the local geology and climate, moisture stress can be a natural occurrence in the area, particularly around sites B and C. Unsurprisingly, the modern landscape is predominantly given over to arable cultivation focused mostly on cereals with pastureland occurring only when water shortages restrict cultivation. On this evidence, the peak period in crop development for revealing cropmarks is assessed to be throughout June and very early in July. However, excesses of precipitation over the spring months combined with the natural conditions may produce local variations: excessive rainfall may delay the cropmark formation by a few weeks, but drought could prevent germination altogether.

Southern Dobrogea has long lived evidence of human occupation since the Neolithic. An area of constant ebb and flow of populations and cultural interference between the classical Mediterranean and the prehistoric Eurasian cultures, Dobrogea, experienced early exposure to the Greek Black Sea colonisation, and subsequent long-lived Roman occupation which eventually dissolved into Byzantine, then Ottoman imperialism. A wide array of man-made features can be found in the archaeological landscape, from those of larger dimensions such as settlement enclosures, roads, large funerary barrows dating from at least the 6th c. BC to the 3rd c. AD, to smaller features including open settlements consisting of small sunken-floored structures or buildings utilising stone walls of sub-metre widths. Archaeological preservation until the 20th century has been fairly good. Although Mangalia has been continuously occupied since its foundation as the Greek colony of Kallatis in the 6th c. BC, ruins have been traditionally subjected only to occasional robbery and accreted settlement, but more recently intensification of arable agriculture and the expansion of urbanism present clear dangers to archaeological preservation. In the cases selected here, ploughing erosion is currently the main danger, but given its location on the fringes of the modern town Mangalia which has seen significant urban expansion throughout the 20th century, site A may soon be engulfed by urban expansion. The wider area has been the focus of research by the first named author during 2004-2007 (*Contextualizing change on the Lower Danube: Roman impact on Daco-Getic landscapes*), funded by the British Academy, which aimed to evaluate the nature and impact of Roman conquest and colonisation on the transformation of native settlement patterns. It involved aerial reconnaissance (June 2005 and 2006) in conjunction with the examination of WWII aerial vertical (1944) and Cold-war Corona satellite imagery (1966) (Oltean & Hanson, 2007b). Several methodological issues were raised. Dealing with an area where aerial reconnaissance had never been applied before meant that estimation of the right time in terms of crop development was constrained and further hindered by the damp seasons in both 2005 and 2006 (in contrast with 2004). As a result, cropmarks were still at their early stage of formation and, although larger structures (e.g. funerary barrows; enclosures) were recognisable, very few stone-built open settlements characteristic of the Hellenistic and Roman periods have been identified. Furthermore, although the archived historical aerial and satellite imagery consulted enabled the recovery of numerous features (visible as soilmarks) and the reconstruction of large parts of the archaeological landscape, they were less successful in revealing the types of sites severely under-represented in the aerial reconnaissance.

3. DATA PROCESSING AND INTERPRETATION:

Initial data sets from Quickbird (DigitalGlobe) included 2 collects, one from 25 June 2004 (catalogue ID 10100100030CB803) and the second on 18 July 2004 (catalogue ID 10100100031E5101). The June collect would be considered ideal for aerial reconnaissance, however the July collect would normally be considered slightly too late in the season, with a lot of cereal crops already being harvested. Both collects included multispectral (4 bands: blue 479.5, green 546.5, red 654 and near-infrared 814.5) and panchromatic imaging Our intention is to analyse the data in parallel by utilising both traditional aerial photo-interpretation, and standard remote sensing approaches to identify archaeological features. The processing and analysis of the data is at its beginning, with the immediate objective of selecting the most relevant methods of enhancing feature detection within the multispectral signature, particularly for cropmarks. In such conditions, comparison of the results particularly with data provided by oblique aerial photographs from 2005 and 2006, but also with earlier archival material from 1944 and 1966, is beneficial.

The three sites selected for closer analysis were all located within the areas covered by these various datasets; additionally, comparison with previous results obtained through alternative methodologies could readily be made. In the area of site A a number of large archaeological features have previously been located (see figure 1). They include funerary barrows and roads belonging to the very large area of burials buffering the ancient town of Kallatis, with a number of roads connecting it with the surrounding territory. However, these features were mainly visible as soilmarks, with less certain cropmarks confidently mapped. Also, although other barrows in the vicinity revealed the presence of a surrounding ditch and/or traces of burial chambers or robbing trenches, no such features were visible here. Sites B and C are similar in both morphological characteristics and natural setting, and are separated by only some 700 metres. Aerial reconnaissance over 2005 and 2006 recorded cropmarks of a stone-built settlement, the only example noted in the area under survey. Indeed, given their proximity, it is a strong possibility that they were separate areas of the same settlement (Oltean and Hanson 2007b, 674906-5).

All images were superficially scanned visually using ENVI 4.3 software. The RGB “true colour” multispectral images were subjected to a linear 2% enhancement to increase contrast. In the second scan Band 4 (IR) was run in the green. Several sites were marked for closer concentration based on object figures and lines, noted as contrasting vegetation marks. This secondary processing included a variety of band combinations to ascertain highest contrast and field depth. Band 4 in the red and Band 2 in both the blue and green, with a sharpening mask and linear 2% stretch initially proved to highlight the features of interest most consistently. A contour line filter was applied to distinguish real surface variation from colour features, however the dense background clutter (plough marks) could not be reliably extracted and the resulting image was difficult to interpret and potentially misleading. A Normalized Difference Vegetation Index (NDVI) analysis was run to highlight real vegetation differences and determine which feature patterns did not register. Once the three sites of highest interest were selected, further analyses were run with ENVI 4.5 and ENVI Zoom 4.5 feature extraction processing tool. An attempt was made on site A to cluster and segment the features visible in the RGB image, but plough mark interference (as with the contour lines) made segmentation and merging nearly impossible. Anomaly detection performed better but provided no new information. Sites B and C features were too obscured to easily use the feature extraction tool (requiring manual segmentation of visible objects). Processed images of site A were run through the feature extractor also with little success still apparently due to clutter. A scatterplot analysis helped to determine the boundaries of apparent features. Two very clear features appeared in site A and no distinct features were apparent with sites B and C, further confirming the visible contrast. Several further processing techniques using standard ENVI internal algorithms were applied with extremely consistent results on all three sites: k-means classification (Richards & Jia, 2005), vegetation suppression and colour mapping. NDVI with a Gaussian stretch enhancement provided the best grayscale contrast (figure 2). Individual band histogram adjustment (interactive stretching) provided the best small feature distinctions as well as a depth of field showing differentiation of previously homogenous features - mostly linear.

For independent analysis based exclusively on this methodology, the results produced by the processing methods discussed above are fairly limited and, especially in the case of sites B and C, insufficient for any confident selection of features. Moreover, the occasional interference from plough marks or other disturbances would prevent any automatic feature extraction. However, when compared with data provided by aerial reconnaissance and the Corona satellite, it is possible to identify several archaeological features in the QuickBird imagery and even to refine and complete the site plans reconstructed previously. Although in the area of site A the panchromatic dataset from 25th June was not sufficiently contrasting to enable identification of cropmarks, the multispectral set revealed the presence of differential vegetation growth signalling larger buried features such as Roman roads, ancient funerary barrows and field boundaries previously noted on aerial photographs and Corona imagery, enhanced by both the application of the vegetation suppression algorithm and the NDVI. Sufficient contrast in vegetation suppression was not

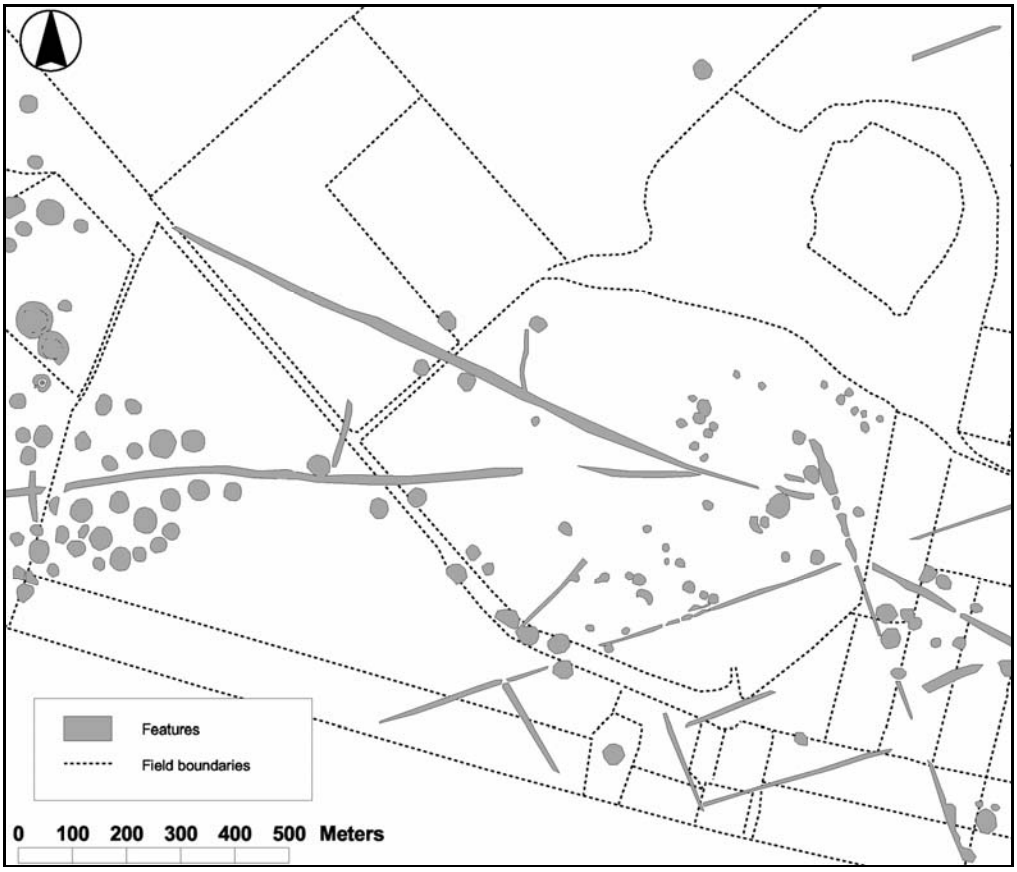


Figure 1. Site A: plan of buried features revealed in the area by aerial photographs from June 2005-2006 and by Corona satellite imagery from April 1966.

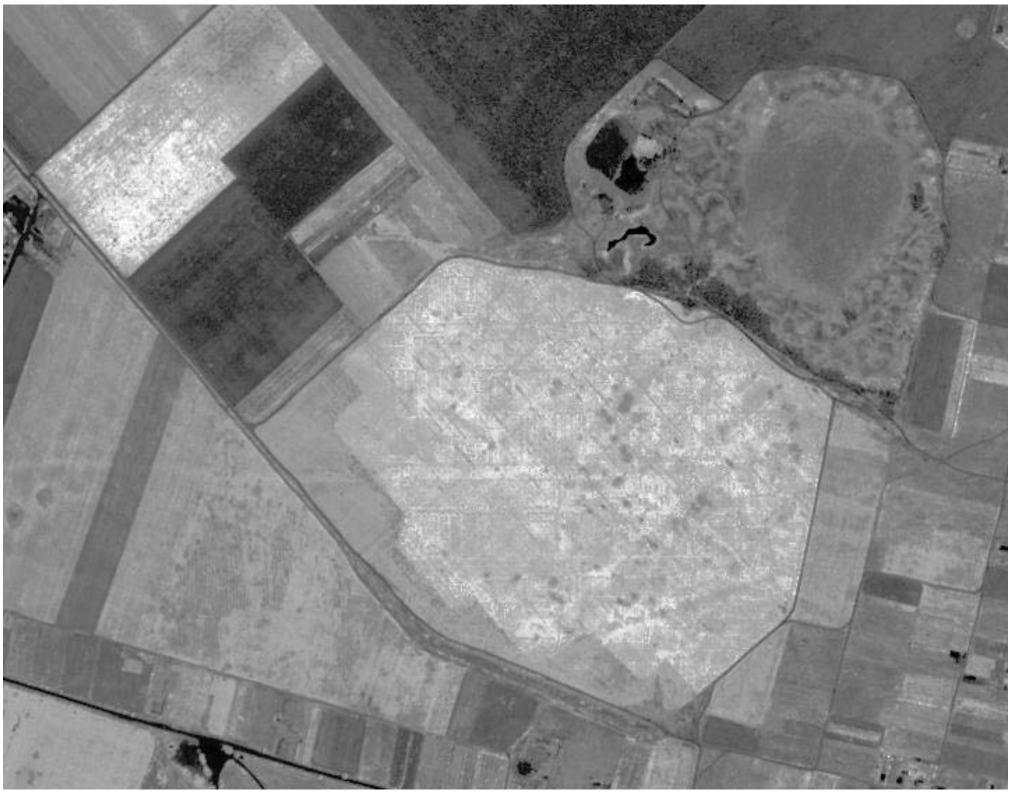


Figure 2. Site A: NDVI analysis of the multispectral collect of 18th July 2004 revealing the presence of buried features.

maintained in July (given the nature of the crop - corn/maize), but the NDVI algorithm was able to reveal further possible features of smaller dimensions which are consistent with a set of possible features revealed by oblique aerial photographs one year after in 2005, though not by Corona images of the site in 1966. However, additional confirmation is needed. Interpretation of the panchromatic imagery available for sites B and C was difficult, given that both were also covered at the time of data acquisition by vegetation not conducive to cropmark formation, and the multispectral data sets produced more limited results in terms of independent recognition of buried archaeological features (probably because of the nature of the site, consisting of buried remains of ancient buildings with sub-metre stone walls). However, comparison of the k-means classification and of the colour mapping applied to the multispectral dataset with the set of features already mapped at site B from aerial photographs enabled the recognition of a few of these features and more importantly, of potential features spreading immediately outside the areas previously mapped. Therefore, this lends further weight to the possibility that site B extends beyond the limits to which its site plan was already reconstructed. One further important outcome is that in both areas of sites A and B, the processing of multispectral data revealed the presence of some archaeological features *despite* the difficult vegetation coverage which may have prevented traditional aerial reconnaissance from delivering good data at a comparable acquisition time.

Our intention is to try further methods of analysis for this data or similar such as the VARI algorithm (vegetation index sensitive to water content and indicative of relative greenness) and principle components analyses to attempt to filter surface clutter. Data fusion (using the pan imagery to enhance the multispectral or multiple processed images) has enormous potential for artificially increasing ground resolution. A project currently being undertaken is the artificial resolution enhancement of low-resolution imagery based on deconstruction models. Once these algorithms have been fully established, these images could provide an excellent test dataset. Additionally, software to automate object detection in cultural heritage sites is being reviewed and the imagery may again be used as a test dataset. Both techniques have enormous potential for archaeology. Once these problems are addressed, the next step will be to attempt viable solutions to apply this methodology to larger areas in the region, in order to assist reconstruction of archaeological landscape.

REFERENCES:

Bewley, R.H., Raczkowski, W. (eds.) 2001. *Aerial archaeology - developing future practic*e, Nato Science Series, Amsterdam.

British Academy, 2001. *Aerial survey for archaeology. Report of a British Academy working party 1999*, London.

De Laet, V., Paulissen, E., Meuleman, K., Waelkens, M. 2007. The effect of pixel resolution and spectral characeristics on the extraction of archaeological features from very high-resolution remote sensing imagery: Sagalassos, southwest Turkey, in M. Ehlers and U. Michel (eds). - *Remote Sensing for Environmental Monitoring, GIS Applications, and Geology VII (Proceedings of SPIE* 6749), 67490A

ENVI *Environment for Visualizing Images*, image analysis software, ed 4.5 released 18 August 2008

Hanson, W.S. 2005 Sun, sand and see: creating bias in the archaeological record, in Brophy, K. and Cowley, D. (eds) *From the air: understanding aerial archaeology*, Stroud: 73-85.

Lasaponara, R., Masini, N. 2006. On the potential of QuickBird data for archaeological prospection, *International Journal of Remote Sensing* 27, 16/20: 3607-3614.

Lasaponara, R., Masini, N. 2007. Detection of archaeological crop marks by using satellite QuickBird multispectral imagery, *Journal of Archaeological Science*, 34: 214-221.

Richards, J., Jia, X. 2005. *Remote Sensing Digital Image Analysis: An Introduction.* 4th ed., Springer

Olsen, R.C. 2007. *Remote Sensing from Air and Space*, Jan 22, SPIE Press

Oltean, I.A., Hanson, W.S. 2007a. Cropmark formation on "difficult" soils in Romania, in J. Mills and R. Palmer, *Populating clay landscapes*, Tempus, Stroud, 73-87

Oltean, I.A., Hanson, W.S. 2007b. Reconstructing the archaeological landscape of Southern Dobrogea: integrating imagery, in M. Ehlers and U. Michel (eds). - *Remote Sensing for Environmental Monitoring, GIS Applications, and Geology VII (Proceedings of SPIE* 6749), 674906

Palmer, R. 2005. If they used their own photographs they wouldn't take them like that, in Brophy, K. and Cowley, D. (eds) *From the air. Understanding aerial archaeology*, Stroud, 94-116.

Remote sensing for recording past landscapes of the Mesopotamian alluvial plain

J. Walstra[1], V.M.A. Heyvaert[2], P. Verkinderen[1]

1 Dept. of Languages & Cultures of the Near East & North Africa, Ghent University, Sint-Pietersplein 6, B-9000 Ghent, Belgium, emails: Jan.Walstra@UGent.be, Peter.Verkinderen@UGent.be

2 Geological Survey of Belgium, Royal Belgian Institute for Natural Sciences, vanessa.heyvaert@naturalsciences.be

Keywords: Geo-archaeology, Landscape evolution, Mesopotamia, CORONA

ABSTRACT:
This paper describes the role of remote sensing within the multidisciplinary research on landscape evolution of the Mesopotamian plain. Traditional sources, such as texts and archaeological surveys, only provide scattered pieces of information. Remote sensing provides the geographical context of these data, interconnecting them and expanding into inaccessible areas. As a result of the continuing developments in remote sensing and information technology, more and better data become available, that are increasingly accessible for analysis.

A short introduction is given to the various types of remote sensing data, and their value within this project. Recent imagery is used to identify present landscape components and serve as a geo-reference for older material. Declassified CORONA images provide an impression of the landscape prior to large-scale landscape changes. In addition, elevation data acquired by the Shuttle Radar Topographic Mission show the patterns of large levee systems throughout the Mesopotamian plain.

Preliminary results are presented from a case-study dealing with the integration of remote sensing, geological, archaeological and historical data to reconstruct the palaeoenvironment of the Lower Khuzestan plain (SW Iran). Use of remote sensing data is proven to be necessary, given the vastness and limited accessibility of the area. This study in particular demonstrates the great value of archival CORONA imagery, as many of the ancient landscape features are destroyed by recent large-scale land development projects. Analysis of CORONA images revealed several ancient river channels and irrigation networks. Integration with archaeological data and historical evidence allowed reconstruction of the chronology of the various channel shifts.

This paper clearly demonstrates the advantage of a multi-disciplinary approach in reconstructing the complex history of the Mesopotamian alluvial plain. Use of remote sensing techniques provides an invaluable tool in such studies, even more so since large parts of the region are currently inaccessible for field surveying.

1 INTRODUCTION

The Mesopotamian alluvial plain was home to the world's first civilizations. The plain is a meeting point of several major rivers, which were the lifelines of these early societies. River patterns continuously changed throughout the Holocene through complex interactions between climate, sea-level, sediment supply, tectonics and human interference. Consequently, ancient settlement patterns are closely related to abandoned river belts. Archaeological surveys and ancient text sources have provided knowledge of these early civilizations. However, a full understanding of their development also requires study of their context within the evolving landscape.

2 REMOTE SENSING DATA

Remote sensing is an established tool in landscape studies; it provides a representation of the earth surface at high spatial and temporal resolutions. Within this project, remote sensing data serves two primary goals:

- Mapping and monitoring of present landscape processes, identifying the basic components of the landscape and providing a base for landscape evolution models.
- Detection and mapping of past landscape features, such as archaeological sites, abandoned river courses and ancient canal systems.

The collected spatial data is used to identify signature features in order to untangle the landscape stratigraphy. Integration with other data sources (historical texts, geological and archaeological surveys) allows a reconstruction of the landscape evolution through time.

Each in a different way according to their specific characteristics, a range of source material can be used:

- SPOT and Landsat imagery is well-suited for the preparation of regional base maps of the modern landscape; recent imagery is available for free via internet and with coverage of the entire region.

- CORONA images provide a record of the landscape, just before many features were destroyed by large-scale land development and irrigation projects in extensive parts of the Mesopotamian plain; the images can be searched and ordered via internet and are relatively cheap; CORONA images have been successfully used for archaeological prospection in Syria (e.g. Donoghue *et al.* 2002) and Central Mesopotamia (Hritz 2005).
- Aerial photographs provide best resolution data, but are rarely accessible. High-resolution satellite imagery, such as Ikonos or QuickBird, would be a good alternative (e.g. De Laet *et al.* 2007), but are far too expensive for the vastness of the research area.
- The Shuttle Radar Topographic Mission (SRTM) provides global elevation data, showing patterns of large levee systems throughout the Mesopotamian plain (Hritz & Wilkinson 2006).

3 LOWER KHUZESTAN CASE-STUDY

Aim of this case-study is the integration of geomorphological, stratigraphical, archaeological and historical data to study the development of the fluvial systems of the Lower Khuzestan plain, SW Iran. This plain is a sedimentary basin, located between the anticlines of Ahwaz and Agha Jari (north/east), the Gulf (south) and the Shatt al-Arab estuary (west). The plain is extremely flat (terrain elevation drops from 8-11 m in the north to 3 m in the south over a distance of 200 km) and dominated by three major rivers: the Karkheh (flowing into the Hawr al-Hawiza marshes), the Karun (joining the Shatt al-Arab) and the Jarrahi (ending in the Shahdegan Marshes).

3.1 *Previous research*

Documentary evidence from the region is scarce, and relies on sources originating outside of it. Information concerning the identification and location of ancient rivers is drawn from a number of sources (Cole & Gasche, 2007; Ooghe, 2007). The earliest sources consist of inscriptions describing the campaigns of Assyrian kings against tribes of southeast Babylonia and Susiana (7th-6th century BC). Classical sources include Greek and Roman historiographers' accounts of the campaigns of Alexander the Great in Babylonia and Persia (4th century BC). Arabic sources comprise historiographical accounts of rebellions and military campaigns in the region, and geographical descriptions of rivers and towns (9th-14th century AD). A last category includes Arabic, Persian and European traveller's accounts (10th-19th century AD).

A limited archaeological field survey around Ahwaz was carried out in 2004 (Gasche & Paymani, 2005), but field data remain fragmentary due to difficult accessibility of the area.

Also in 2004, a geological field campaign was undertaken. Detailed lithological analyses of sedimentary sequences in boreholes, fingerprinting the fluvial stratigraphy and integration with geomorphological data (acquired through interpretation of Landsat images), provided a chronology for palaeochannel belt shifts. Formation of a Karun megafan through repeated avulsions initiated the development of the Mesopotamian brackish-freshwater marshes and controlled to a great extent the Late Holocene progradation of the Lower Khuzestan coastline (Baeteman *et al.*, 2004/2005; Heyvaert & Baeteman, 2007).

3.2 *Interpretation of CORONA imagery*

For this study 16 pairs of high-resolution scanned CORONA images (dated 23/9/1966) were acquired and interpreted. Because of the very little relief in the Khuzestan plain, stereo-viewing proved to be useless and only forward images were used for mapping. As accurate ground control was not available, the images were georeferenced to SPOT images, using a 2nd order polynomial function to allow for the large panoramic image distortions. Georeferencing and mapping were carried out in ArcMap 9.2.

The CORONA images proved to reveal much more information than the Landsat images used in a previous study – not only allows their higher resolution much smaller features to be identified, but also do they represent the landscape prior to large-scale land development and irrigation projects. Landscape features that were mapped included meandering palaeochannels, crevasse splays and ancient canal systems (see Figures 1 and 2). A drawback of the CORONA images, due to their limited image resolution and contrast, is the difficulty in detecting small archaeological sites. Some of the sites observed in the field are clearly visible on aerial photographs, but remain ambiguous on CORONA imagery.

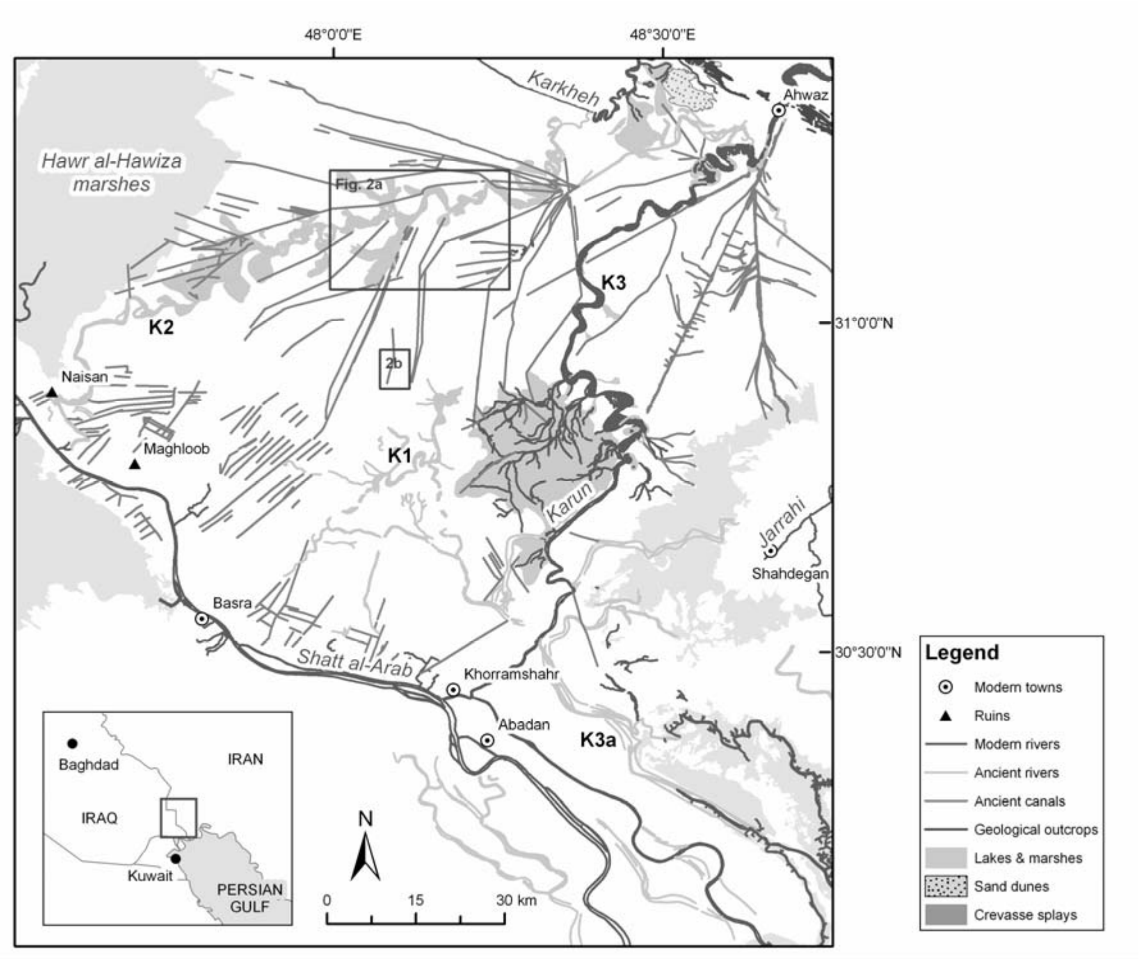


Figure 1. Ancient and modern hydrological features mapped from CORONA images. Red boxes indicate the location of the areas shown in Figure 2.

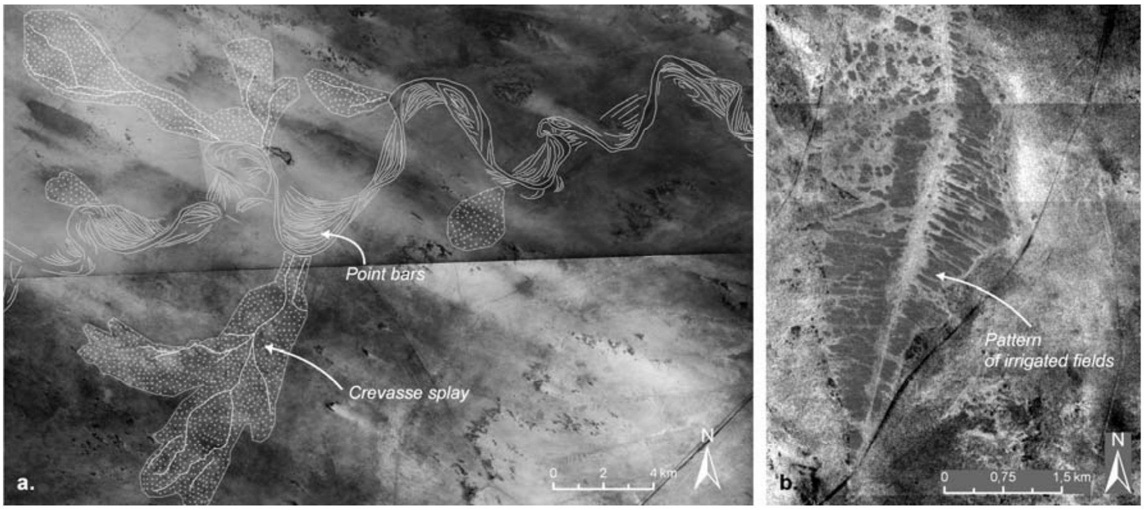


Figure 2. Examples of features mapped from CORONA images: (a) palaeochannel K2, with point bars and crevasse splays; (b) ancient canal with typical pattern of irrigated fields.

3.3 *Integration of datasets*

Three large channel belts belonging to the Karun were distinguished (figure 1). The K3 corresponds to the present-day Karun channel. It is known from maps and European travellers' accounts that the K3 branch followed a different course in its downstream section up to the late 18th century (K3a). This older course, called

‘Blind Karun’ since it ran dry, flowed directly into the Gulf, rather than joining the Shatt al-Arab at Khorramshahr. The K2 branch can be linked to the ancient Karun described in old texts as flowing into the Tigris near Alexandria-on-the-Tigris/Spasinou Charax (present ruins of Naisan). The position of the K1 branch within this chronology is uncertain and requires further investigation. The presence of extensive irrigation networks suggests that human intervention might have controlled the various channel shifts. Superimposition of the canal networks and their connection to ancient river branches allows relative dating of the various systems.

4 CONCLUSION

This paper clearly demonstrates the advantage of a multi-disciplinary approach in reconstructing the complex history of the Mesopotamian alluvial plain. Remote sensing is an invaluable tool in such studies, even more so since large parts of the region are currently inaccessible for field surveying.

5 ACKNOWLEDGEMENT

The presented research is undertaken within the framework of the Interuniversity Attraction Pole ‘Greater Mesopotamia: Reconstruction of its Environment and History’ (IAP 6/34), funded by the Belgian Science Policy.

6 REFERENCES

Baeteman, C., Dupin, L. Heyvaert, V.M.A. 2004/2005. Geo-Environmental Investigation. *Akkadica* 125(2): 155-215 & 126(1): 1-12.

Cole, S.W. & Gasche, H. 2007. Documentary and Other Archaeological and Environmental Evidence Bearing on the Identification and Location of the Rivers of Lower Khuzestan and the Position of the Head of the Persian Gulf ca. 1200BC – 200AD. *Akkadica* 128(1-2): 1-72.

De Laet, V., Paulissen, E., Waelkens, M. 2007. Methods for the extraction of archaeological features from very high-resolution Ikonos-2 remote sensing imagery, Hisar (southwest Turkey). *Journal of Archaeological Science*, 34(5): 830-841.

Donoghue, P.G., Beck, A., Galitasatos, N. 2002. CORONA satellite photography: An archaeological application from the Middle East. *Antiquity* 76(291): 109-118.

Gasche, H. & Paymani, A.R. 2007. Repères archéologiques dans le Bas Khuzestan. *Akkadica* 126(1): 13-43.

Heyveart, V.M.A. & Baeteman, C. 2007. Holocene sedimentary evolution and palaeocoastlines of the Lower Khuzestan plain (southwest Iran). *Marine Geology* 242(1-3): 83-108.

Hritz, C. 2005. *Landscape and Settlement in Southern Mesopotamia: A Geo-Archaeological Analysis*. Unpublished PhD thesis. Oriental Institute, University of Chicago, USA.

Hritz, C., Wilkinson, T.J. 2006. Using Shuttle Radar Topography to map ancient water channels in Mesopotamia. *Antiquity* 80(308): 415-424.

Ooghe, B. 2007. *Off the beaten track: Travellers, maps, and the landscapes of Ottoman Mesopotamia.* Unpublished PhD thesis. Dept. of Languages & Cultures of the Near East & North Africa, Ghent University, Belgium.

Lost courses of River Sarasvati and spatial distribution of Harappan settlements – Observations based on multisensor satellite data

M.B.Rajani[1], A.S.Rajawat[2]
1 National Institute of Advanced Studies (NIAS), Indian Institute of Science Campus, Bangalore 560 012, India
rajanihf@gmail.com
2 *Space Application Centre (SAC), Ambawadi Vistar P.O., Jodhpur Tekra, Ahmedabad 380 015, India*
asrajawat@sac.isro.gov.in

Key words: Palaeo-channels, Harappan civilization, Sarasvati, remote sensing, multi sensor studies.

ABSTRACT

The region of north-western India (covering the states of Punjab, Haryana, Gujarat and Rajasthan) and flood plains of river Indus and its tributaries in Pakistan is geographically diverse, geologically active and rich in archaeological sites of Harappan civilization (2500– 500 BC). In the past few decades a large amount of work has been carried out to map palaeochannels in this region using multi sensor satellite data and understand their migration and evolution. These studies have shown evidence of a prominent river system, which has become buried under sand cover of Thar Desert sometime during late Holocene. This major river has been identified as *Sarasvati*, a legendary river mentioned in ancient Indian texts. The present study has analysed multisensor satellite data using digital interpretation techniques in conjunction with Geographical Information System (GIS) to identify and correlate palaeochannels of Sarasvati river and its tributaries with spatial distribution of Harappan settlements. The study could identify new courses of the Sarasvati river and demonstrate that the clusters of Harappan settlements from the mature period to later period have moved in the same direction as the migration of the "Sarasvati river".

1 INTRODUCTION

Rivers have been the lifelines of civilizations, and their evolutions. The study area comprises the Indus basin covering parts of Pakistan and India and in particular the Thar Desert (figure 1). Extensive survey and exploration between 1954 and 1975 have identified around seven hundred sites belonging to different phases of Indus civilization within the political boundaries of India, and in Pakistan about two hundred and fifty sites have been identified. The geographical extent of this culture spreads over 1.5 million sq km extending beyond the confines of Indus Valley, therefore archaeologists have redesignated it as Harappan Culture, named after the first discovered site, Harappa (Rao, 1991). In the west Surkagendor (Makran), in the east Alamgirpur (UP, India), Rupaṛ in the north and Bhagatrav in south Gujarat, India, represent the outer limits of Harappan culture. The total period has also been divided into three: the early Harappan (2500–2200 BC), the mature Harappan (2200–1700 BC) and the later Harappan (1700–around 1500 BC) (Possehl, 1982).

Palaeochannels are remnants of stream channels cut in older rocks/sediments and filled by younger overlying sediments, representing the distribution of valley systems as these existed at a given geological time in the past (Bates *et a.,*1980). Large amount of work has been carried out to map palaeochanels in this region using multi sensor satellite data and understand their migration (Ghose *et al.*, 1979, 1980; Pal *et al.*, 1980; Sood *et al.*, 1983; Ramasamy *et al.*, 1991; Rajawat et al., 1999a, 1999b, 2003, 2005). These studies have shown evidence of a prominent river system, which has become defunct and buried under sand cover of Thar Desert sometime during late Holocene. This system has been identified as *Sarasvati*, a legendary river mentioned in many ancient Indian texts. The Sarasvati river is inferred to flow from Himalayas to Arabian Sea through present states of Punjab, Haryana, Rajasthan, and, in Pakistan, Bahawalpur and Sind. The present study has utilized remote sensing techniques in conjunction with Geographical Information System (GIS) to integrate multiple sensor based identification of palaeochannels and correlation with archaeological site location of two epochs of Harappan culture.

Table 1 : Data utilized for the study.

Resolutions	**Resourcesat-1 AWiFS**	**IRS-P4 OCM**	**IRS-1C/1D WiFS**
Spectral channels (nm)	B1 520 - 590 B1 620 – 680 B2 770 – 860 B3 1155 –1700	B1 402 – 422 B2 433 – 453 B3 480 – 500 B4 500 – 520 B5 545 – 565 B6 660 – 680 B7 745 – 785 B8 845 – 885	B1 620 – 680 B2 770 – 860
Spatial (m)	56	360	188
Swath (km)	740 (from two cameras)	1420	780
Quantisation (bit)	10	12	8

2 DATA AND METHODS

The salient characteristics of wide swath data used in this study are listed in Table 1. IRS-1C/1D LISS III data with spatial resolution of 23.5 m and swath of 148 km were chosen to study selected areas in detail. Processed Digital Elevation Model (DEM) data of Shuttle Radar Topographic Mission (SRTM) covering the study area was analyzed to understand the terrain characteristics in relation with the palaeochannel and archaeological site distribution. Mosaics of OCM (Ocean Colour Monitor) data and WiFS (Wide Field Scanner) data were made. Enhancements and Principal Component Analyses (PCA) were conducted using ERDAS IMAGINE and ENVI softwares. PCA optimizes information from several spectral channels. A database of mature-Harappan and later Harappan, compiled from various published sources (Possehl 1982; Joshi & Bisht 1994; Mughal 1992) was used to generate a GIS layer~~s~~ of location of more than a thousand sites. A subset of the corresponding SRTM DEM data was made. Draping the image layers and site location over the SRTM DEM data 3D views were generated. This made terrain features and relative positions of archaeological sites more clear. Field visits to the identified palaeochannel of the Sarasvati were made and ground truth data was collected.

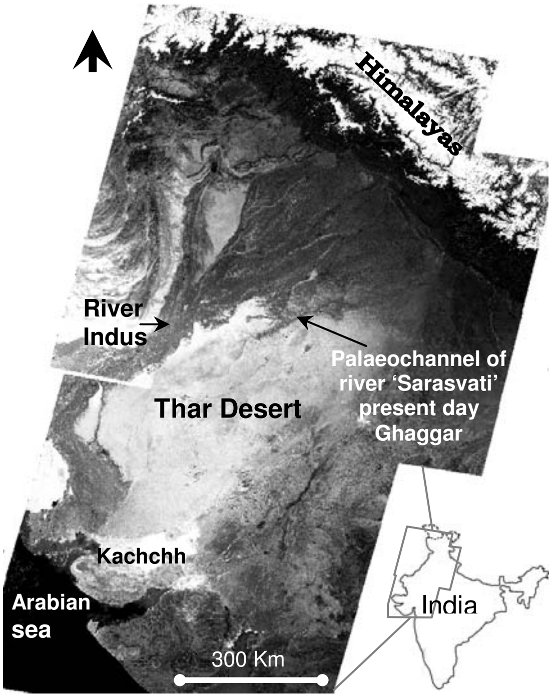


Figure 1. IRS-1C WiFS mosaic providing a synoptic view of the stud area covering the Indus basin and the Thar desert.

3 OBSERVATIONS AND DISCUSSIONS

The WiFS mosaic show the area under study (figure 1), large portion of the study area appears as light bluish to white tone due to the presence of aeolian sand. However, the synoptic cover in this data distinctly shows the pattern of the palaeochannel of the *Sarasvati* river in northwestern India and adjoining parts of Pakistan. Present day dried Ghaggar bed is identified as this palaeochannel in the region.

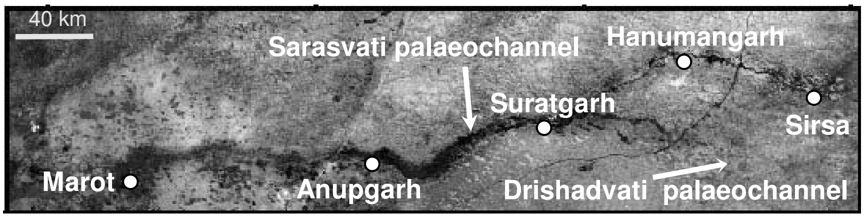


Figure. 2: Digitally enhanced Resourcesat-1 AWiFS PC Colour Composite showing the palaeochannels of the Sarasvati and the Drishadvati rivers in the northern parts of Rajasthan and adjoining region of Pakistan.

The palaeochannel of the *Sarasvati*, in the northern parts of Rajasthan has been digitally enhanced using Principal Components 1, 2 and 3 (as RGB) of Resourcesat-1 AWiFS data (figure 2). Apart from the course of Sarasvati, a palaeochannel of its tributary the *Drishadvati* river is distinctly enhanced. The bed of this palaeochannel is 1-1.5 km wide. The palaeochannel of the Sarasvati is around 6-8 km wide and it is difficult to visualize in field due to extensive cultivation, however it is easily identifiable due to synoptic view provided by the satellite data. These palaeochannels are not shown on corresponding topographical maps at 1:50,000 scale.

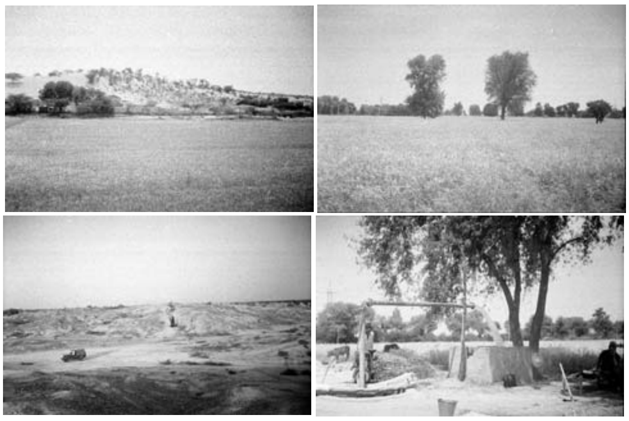


Figure 3: Field photographs of the Sarasvati bed near Suratgarh in Rajasthan showing wheat crop, archaeological mound and high ground water yield near Suratgarh in Rajasthan

A reconnaissance field visit was made to collect field observations along the Sarasvati palaeochannel bed in the Hanumangarh–Suratgarh–Anupgarh sector. The contrast on the satellite data is provided by the sand dunes at the banks along the palaeochannel and by the luxuriant growth of wheat confined to the 6-8 km wide river bed. All along the bank of the palaeochannel several mounds suggesting archaeological sites are observed. The groundwater occurrence is excellent (6000–15, 000 gph in Dug-cum-bore wells) and quality of ground water is potable (700–4520 µ siement/cm E.C.) and confined to the palaeochannel bed (figure 3).

Apart from enhancing the known courses of the Sarasvati river along Ghaggar in the northern Rajasthan, Haryana and Punjab, new courses of the lost Sarasvati river could be identified along Indo-Pak border in Western Rajasthan. Two possible traces of this river are demarcated (figure 4): eastern trace passes through the Jaisalmer district of Western Rajasthan where ground water potential zone is present and western trace passes through the adjoining region in Pakistan.

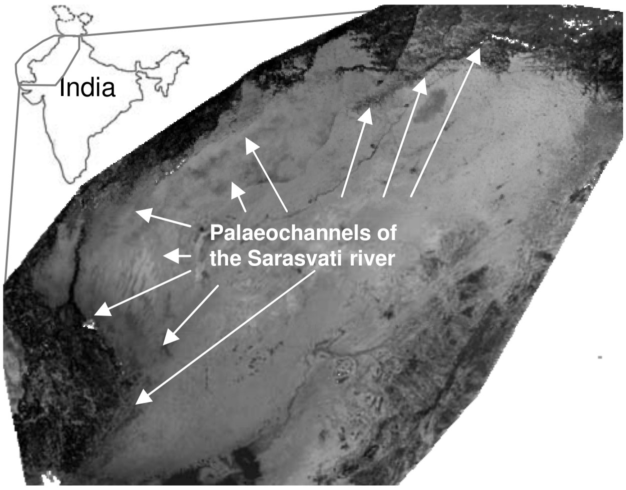


Figure 4. Digitally enhanced IRS-P4 OCM PC 321 showing the palaeochannels of the Sarasvati river through the sand dune area of Western Rajasthan and adjoining parts of the Pakistan

4 SPATIAL DISTRIBUTION OF HARAPPAN SITES AND THEIR RELATION TO PAL AEOCHANNELS

Joshi et al. (1994) have compiled the data on Harappan sites in India. Mughal (1982) has mapped 414 sites in a 16-24 km wide strip along the Hakra bed in Cholistan desert (Bahawalpur) extending over a distance of 480 km starting from Fort Abbas on Indo-Pakistan border to Rahim Yar Khan, Pakistan. Sahai (1999) has attempted to superpose location of Harappan sites on the palaeochannels as deciphered by Pal et al. (1980) using GIS environment. In the present study we have superimposed mature and late Harappan sites on Resourcesat-1 AWiFS data covering the entire Sarasvati basin in the north-western Indian subcontinent (figure 5). The observations show that there is fairly good distribution of Mature Harappan along the Sarasvati and the Drishadvati palaeochannels in northern Rajasthan and Bahawalpur region of Pakistan.

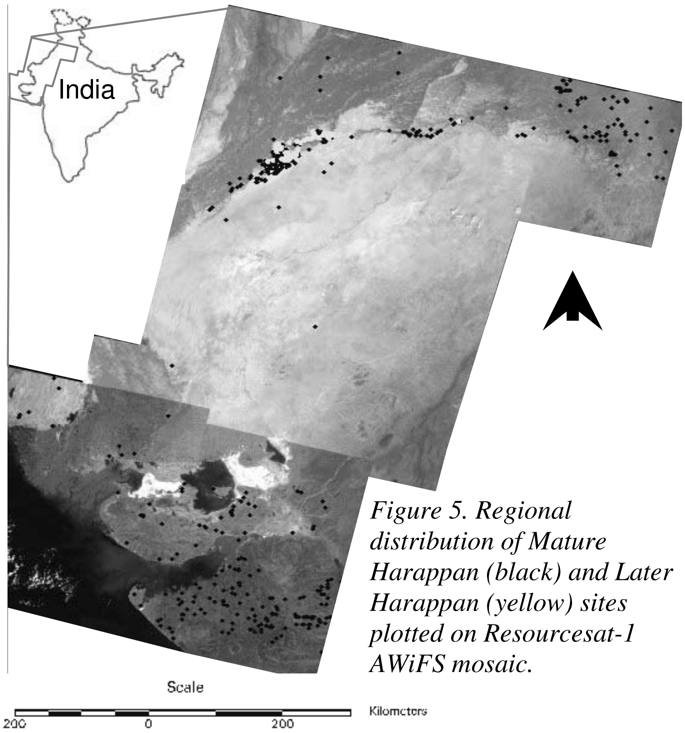


Figure 5. Regional distribution of Mature Harappan (black) and Later Harappan (yellow) sites plotted on Resourcesat-1 AWiFS mosaic.

The distribution of Late Harappan sites is mainly along the Bahawalpur region in Pakistan. Late Harappan sites are not observed along the palaeochannel of Sarasvati river and parts of the upper Indo-Gangetic plain indicating that by this time the Sarasvati bed must have dried. A large number of Mature Harappan sites are observed in the Kachchh and Saurashtra peninsula in Gujarat state (figure 5). Figure 6 show a 3D view of palaeochannel of the Sarasvati (Ghaggar region) seen on IRS 1D LISS-III along with Mature Harappan sites plotted as black dots. These sites occupy the adjoining relict natural levees seen as raised mounds. Most of the sites are located at the fringe of the Thar desert (western boundary) with the Indo-Gangetic plain It is observed that only five or six mature Harappan sites are located within the aeolian cover of Thar Desert seen as bluish-white tone of AWiFS FCC mosaic. Five of these sites coincide with courses of the Sarasvati river, further exploration along the identified courses of the Sarasvati river may yield fruitful results. The reduction in the number of sites between the mature and late period and also the shrinkage in the geographical area covered by late-Harappan sites as compared with the mature Harappan ones is very significant. A large number of sites of the mature period must have ceased to exist, may be due to the channels' drying up and not having sufficient water supply for sustenance of the cities. The inhabitants of these sites might have abandoned them and migrated elsewhere. The cluster of sites in the region further west might have lasted into later period because of continued supply of water although from a different course. The area in Pakistan where there is a cluster of later sites has a cluster of mature period sites too. It could be due to the water supply to this area continuing for longer. These are questions for further investigation. One would raise also the possibility of palaeoclimatic changes and related studies for detailed investigation.

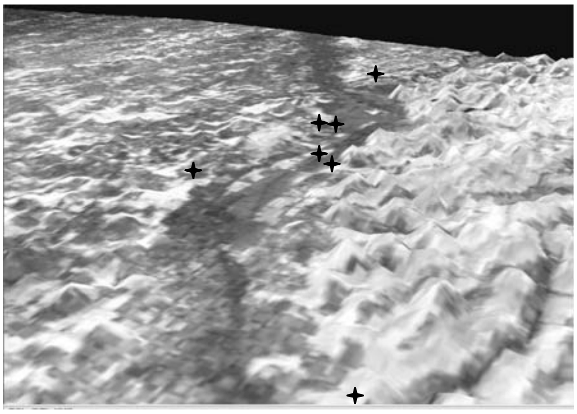


Figure 6. 3D fly-through over the palaeochannel of the Sarasvati seen on IRS 1D LISS-III along with Mature Harappan sites plotted as black dots.

5 CONCLUSIONS

The synoptic view provided by the large swath of OCM, AWiFS and WiFS data and application of digital enhancements techniques were useful to identify lost courses of the Sarasvati and Drishadvati rivers, and in understanding clusters of archaeological sites in context of their relationship with migrating river courses, climatic changes and human settlement patterns over a period of time. SRTM DEM data provided relief information and 3D terrain models could be used for better interpretation of 2D satellite data for palaeochannel studies and archaeological investigations. The demarcated traces of palaeochannels of Sarasvati together with a cluster of Mature Harappan sites found along suggests further archaeological exploration might yield fruitful results

6 REFERENCES

Bates, R.L., Jackson, J.A. (Eds) 1980. *Glossary of Geology*, American Geological Institute, Falls Church, Virginia.

Ghose, B., Kar, A., Hussain, Z. 1979. The lost courses of the Sarasvati river in the Great Indian desert: New Evidence from the Landsat imagery. *The Geographical Jour.,* London, 145(3):446-451.

Ghose B., Kar, A., Hussain, Z. 1980. Comparative role of Aravalli and the Himalayan river systems in the fluvial sedimentation of the Rajasthan desert. *Man and Environment*, 4:8-12.

Joshi, J.P., Bisht, R.S. 1994. *India and the Indus civilization*, National Museum Institute, New Delhi.

Mughal, M.R. 1992. The geographical extent of the Indus Civilization during the Early, Mature and Late Harappan times, In: G.L. Possehl, ed. *South Asian archaeological studies*, Oxford and IBH, New Delhi, pp 123-143.

Mughal, M.R. 1982. Recent Archaeological Research in the Cholistan Desert'. In, Possehl, G. L. (ed.), *Harappan Civilization: A Contemporary Perspective*. Oxford & IBH Publishing Co., New Delhi, Bombay, Calcutta: 85-95.

Pal, Y., Sahai Baldev, Sood, R.K., Agarwal, D.P. 1980. Remote sensing of the 'lost' Saraswati river. *Proc. Ind. Acad. Sci. (Earth and Planet Sci.)*, 89(3):317-331.

Possehl, Gregory L. 1982. *Harappan civilization, a contemporary perspective*, Oxford and IBH Publishing Co.

Rajawat, A.S. 2005. Reconstruction, evolution and significance of palaeodrainage network in Western Rajasthan: An investigation based on multisensor satellite data and Geographic Information System (GIS); Unpublished *PhD Thesis, Vikram University, Ujjain*, 331 p.

Rajawat, A.S., Verma, P.K., Shailesh Nayak 2003. Reconstruction of palaeodrainage network in northwest India: Retrospect and Prospects of remote sensing based studies; *Proc. Indian National Science Academy*; 69A(2):217-230.

Rajawat, A.S., Narayan, A., Navalgund, R.R., Pathak, S., Sharma, J.R., Soni, V., Babel, M.K., Srivastava, K.S., Sharma, D.C. 1999. Potential of Radar (ERS-1/2 SAR) and high resolution IRS 1-C data in reconstruction of palaeodrainage network in western Rajasthan, *Memoir of the Geological Society of India*, no. 42, pp. 245-258.

Rajawat, A.S., Sastry, C.V.S., and Narayan, A. (1999). Applications on Pyramidal processing on high resolution IRS 1-C data for tracing migration of the Sarasvati river in parts of Thar desert, *Memoir of the Geological Society of India*, no. 42, pp. 259-272.

Rao, S.R. 1991. *Dawn and devolution of the Indus civilization*, Aditya Prakashan, New Delhi.

Sahai, B. 1999. Unravelling of the 'Lost' Vedic Sarasvati. In *Vedic Sarasvati, evolutionary history of a lost reiver of northwest India*, Memoir of Geological Survey of India, Bangalore, No. 42, pp 121-141.

Sood, R.K. Sahai, B. 1983. Hydrographic changes in northwestern India. *Man and Environment*, 7:166-169.

Ramasamy, S.M., Bakliwal, P.C., Verma, R.P. 1991. Remote sensing and river migration in Western India. *Intl. J. of Remote Sensing*, 12:2597-2609.

ACKNOWLEDGEMENTS:

The authors are thankful to Dr. K. Kasturirangan, Director, NIAS, and Dr. R.R. Navalgund, Director, SAC, for their overall guidance, Institutional support and encouragement in carrying out the present study. We are also thankful to Prof. B.V. Sreekantan at NIAS for useful discussions. The second author is thankful to Dr. Shailesh Nayak, Director, INCOIS, Hyderabad and Prof. P.K. Verma, Vikram University, Ujjain for guidance in some of the work reported in this paper.

The morpho-topographic and cartographic analysis using GIS and Remote Sensing techniques of the archaeological site Cornesti "Iarcuri", Timis County, Romania

D. Micle, M. Török-Oance, L. Măruia
West University of Timisoara, Department of History, Bv. V. Parvan nr.2-4, 300223 Timisoara, Romania.
E-mail: dmicle@litere.uvt.ro, torok@cbg.uvt.ro, lmaruia@litere.uvt.ro

Keywords: remote sensing, landscape archaeology, fortification, GIS, environmental archaeology

ABSTRACT:
The archaeological site Cornesti "Iarcuri" is the largest earth fortification in Romania, made out of four concentric compounds, spreading over 1780 hectares. It is known since 1700, but it had only a few small attempts of systematic research, the fortress gained interest only after the publishing of some satellite images by Google Earth. It is located in an area of high fields and it occupies three interfluves and contains two streams. Our paper contains a geomorphologic, topographic and cartographic analysis of the site in order to determine the limits, the structure, the morphology, the construction technique and the functionality of such a fortification. Our research is based on satellite image analysis, on archaeological topography, on soil, climate and vegetation analysis and also on geophysical prospecting (magnetometry) as a way to offer a complex image, through this interdisciplinary study of landscape archaeology. Through our work we try not to date the site as this objective will be achieved only after completing the systematic excavations which started in 2007, but only to analyze the co-relationship with the environment.

The archaeological site from Corneşti "Iarcuri[1]" is a fortification made up of four concentric waves of earth that takes up a surface of 1780.5 ha. Due to the fact that the only archaeological evidence are the waves of earth and the surface on which the fortification lies is enormous, the fortification from Corneşti "Iarcuri" has been ignored for a very long time and it is almost unknown in specialized literature (Medeleț, 1993; Micle *et al.*, 2006). Located approximately between the settlements of Corneşti (to the South - West), Orțişoara (to the North - West), Murani (to the South – East) and Seceani (to the North - East), the fortification is in the Eastern vicinity of the European way E671, from where one can see the Western side of the enclosure wave no. 4

The great size of the fortification makes it visible as a whole only from great heights. In this sense, a first aerophotogrammetric analysis was conducted in 1988 by M. Rada, N. Ciochină and D. Manea (Rada *et al.*, 1989), who for the first time talk about the possible existence of four fortified enclosures.

Between 2005 and 2006 a team of researchers from the West University of Timisoara, the History Department (Dorel Micle, Liviu Măruia) and the Geography Department (Marcel Török-Oance), started a scientific activity of archaeological research on the field. The research was started as a result of identifying, on satellite images with the help of *Google Earth* (DigitalGlobe images), the entire archaeological complex. The objective was to establish exactly the lining of the waves from the four enclosures of the fortification, to identify all the possible settlements that have existed through time in this space and to collect archaeological material from the surface that would contribute to a better dating and cultural assigning (Micle *et al.*, 2006). The team verified on the field the data provided by the satellite images, in the spots in which revealing clues (color, shapes, humidity and vegetation) suggested possible human intervention (Fig. 1).

The fortification appears on most maps that present the historical and geographical region of Banat, starting with the 18th century, but none of these maps provide a correct image of the size and lining of the archaeological complex of Corneşti. In the perspective in which the start of systematic archaeological investigations – that would clarify the complex issues that a site of this amplitude raises (chronology, ethnic assignment, function, etc.) – is required, our team of researchers has conducted a preliminary interdisciplinary analysis aiming at corroborating the data provided by the satellite images, air photos, cartography, geomorphology and pedology.

A Digital Elevation Model – DEM was made both for the morphometric analysis and for building a data base of the spatial values of the studied area. The making of a DEM, starting from the existing maps and topographic plans, supposes the transposition of the altitude values of the topographic map in digital format and the insertion of the existing values by mathematical methods. For the making of this model topographic maps on the scale of 1:25000 were used as data sources. These maps were scanned, referenced geographically in the national coordinate system Stereo 1970 and inlaid. Through manual digitizing of all curve levels and elevation points (with the help of the ArcGIS 9.2 program) the altitude values were extracted and interlaid by the Delauney method. We used the method of contracting the insertions between the curve levels and we eliminated the errors of insertion generated by the insufficiency of altitude data in some areas with the option "*bridge and tunnel edge removal*" of the program IDRISI Andes (Eastman 2006). A representation of the relief was thus achieved by the means of a network of irregular triangles known as TIN (*Triangular Irregular Network*). This was subsequently transformed into a raster model, achieving the numeric model of the field (DEM) with a 2 m resolution (a pixel of the image corresponds to a 2 X 2 m surface on the field). For a better image of the earth waves DEM was improved by using the altitude data gathered on the field (figure 2).

---

[1] **iarc**, *iárcuri,* s.n. (reg.) large border ditch. In local toponimy "iarc" means a large border ditch, elevation of the ground, earth wave, and it is found as a toponim in other places in Banat region.

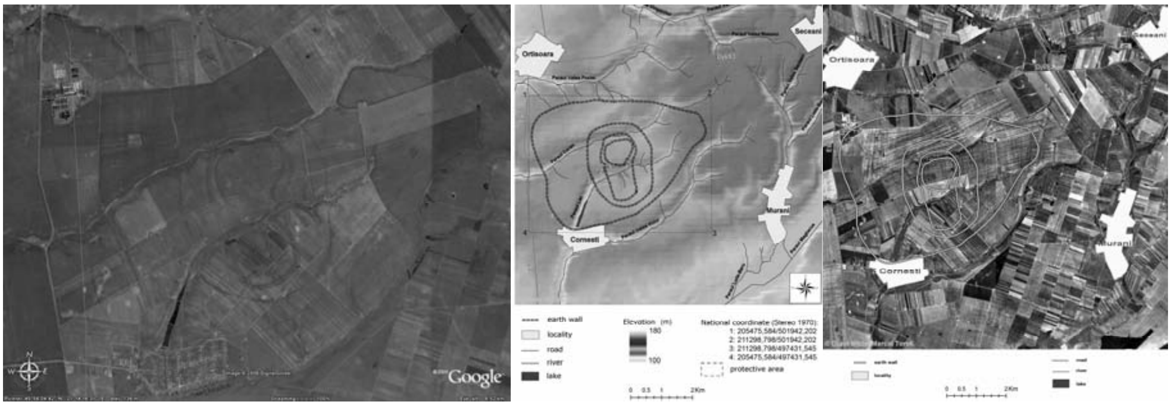


Figure 1-3 Archeological site Corneşti "Iarcuri". (left). Google Earth (DigitalGlobe image). (Centre) Digital Elevation Model. (Right) Orthophotoplan

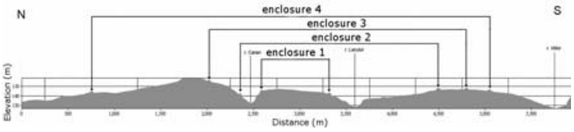
The other elements of the spatial data base (layers of hydrographic network, the roads, the contour of the earth waves and the living areas) were digitized from the color orthophotoplans because these are the most recent cartographic sources, and the scale of 1:5000, enables the examination of all the details (Fig. 3). With the help of the DEM a morphometric analysis of the region was made, by analyzing the following morphometric elements: the hypsometry, the slope and the aspect (surface lining). All the morphometric data are synthesized in table 1. DEM was used for the making of 2 topographic profiles (figures 4 and 5), one on the lining North - South and the other East – West, and for the visual analysis of the studied region (2D and 3D illustrations).

Area	**Surface (km^2)**	**Surface (ha)**	**Perimeter (km)**	**Long axis (km)**	**Short axis (km)**	**Altitude (m)**				**Slope (grades)**			**Exposure (grades)**
						Min.	**Max.**	**Medium**	**Amplitude**	**Min.**	**Max.**	**Medium**	**Medium**
The entire area	89,35	8935,86	-	-	-	97,6	184,65	145,46	87,04	0	56,59	2,21	203,08
Enclosure 1	0,71	71,04	3,01	1,05	0,94	134,94	147,51	144,67	12,57	0,01	9,08	0,96	190,85
Enclosure 2	1,43	143,28	9,09	2,24	1,25	125,4	148,04	139,38	22,64	0,02	19,40	2,78	195,01
Enclosure 3	2,89	289,08	14,15	2,82	2,23	158,30	125,24	142,72	33,05	0	17,74	2,35	206,24
Enclosure 4	12,68	1268,18	24,25	5,72	4,15	117,35	168,56	145,50	51,21	0	39,36	1,68	217,90
The site (all enclosures)	17,80	1780,5	-	5,72	4,15	117,35	168,56	144,51	51,21	0	39,36	1,85	213,06

Table 1. Morphometric data from the DEM for the area in study.

The actual archaeological site takes up an area of 17.8 km^2 (1780,5 ha) and spreads on the three interfluves between the rivers Poştei, Caran, the Lacului river and Valea Viilor (the Vineyard Valley). However, for a better analysis, the entire spatial data base was made for a much wider area, between the settlements of Orţişoara and Seceani to the North and Corneşti and Murani to the South, totalizing 89,35 km^2. The studied area is at the Southern limit of the Vinga Plain (Bizerea, 1973), which is a high plane. At its Southern limit it comes into contact with the low, subsiding Timiş Plain. This explains the variation in altitude from 97.6 m in the South and South-East of the studied area to 184.65 m in the North-Eastern part of it. The relief is made up of smooth, wide interfluves lined up on the East – North-East / West – South – West axis, with medium heights of 140 – 145 m and widths of up to 2600 m, that represent the terraces of the rivers that fragment the plain. The interfluves are separated by the valleys of the rivers Poştei, Caran, Lacului, Valea Viilor and Măgheruş whose valley floors are 20 to 50 m deeper than the interfluves. The valleys have transverse profiles shaped as an open "U", typical of evolved valleys, with the Northern slope more inclined than the

Southern one. The transversal profiles of the valleys are close to the equilibrium profile, except for a sector of the Lacului Valley that present, in the spot in which the second earth wave intersects the valley, a slope rupture of approximately one meter. At the same time there are obvious morphologic differences in the sector upstream from the slope rupture and the one downstream, which suggests the hypothesis that the second earth wave also had the role of a dam at the site of the Lacului Valley. The arguments that support this hypothesis are: (i) the existence of the slope rupture of the transversal profile of the valley, situated exactly in the extension of the second earth wave; (ii) the inexistence of such slope ruptures on the other valleys which suggests the human origin of this one; (iii) the flat aspect of the riverside upstream from the slope rupture, contrasting with the one downstream from the place in discussion, aspect that suggests the existence of a former sedimentation area (the floor of a lake); (iv) the high conservation state if the wave on the slopes and towards their base, as compared to the other areas in which the earth waves intersect the water courses.



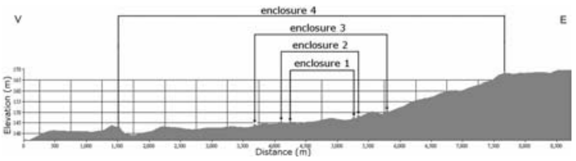
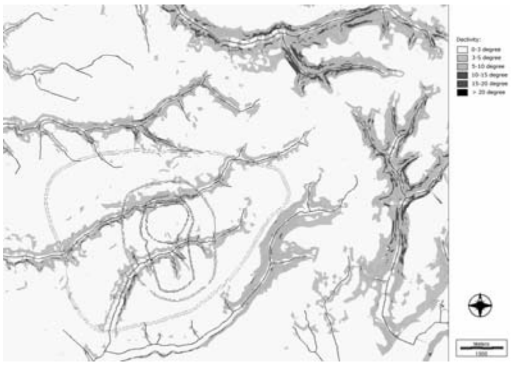


Figure 4 (left). Transversal topographic profile on the N-S axis, between the Poştei and Viilor rivers Figure 5 (right). Longitudinal topographic profile on the W-E axis, on the interfluves between the Caran and Lacului rivers.

The slope representation (figure 6) was generated based on the DEM and enabled the analysis of the declivity values for the entire area and for each enclosure separately (table 1). Because of the fact that most of the area is taken by the wide and smooth interfluves the medium value of the slope is 2.21, from which the majority consists of the slopes with declivity values below 5 degrees (75 km^2). The highest values, of over 10-15 degrees, are characteristic of the valley slopes and take up a surface of only 2 km^2. An interesting situation of the distribution of the declivity values is given by the actual presence of the earth waves, which, according to the height and width, lead to the appearance of slopes of more than 5, 10 and even 20 degrees. This is why the earth waves are perfectly visible on the slope representation. The aspect represents the line on which the slope has its maximum value. It can be defined as "the direction of the horizontal projection of the surface normal of the slope and it is measured clockwise, referring to the direction of the geographical North" (Donisă *et al.*, 1998).



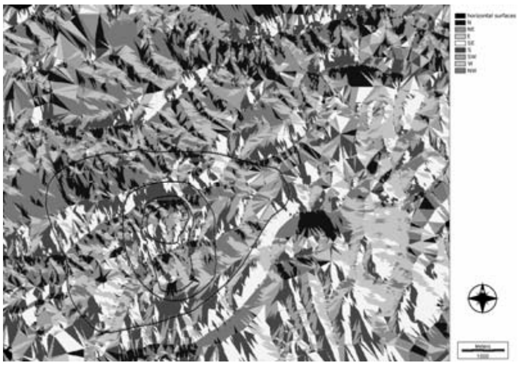
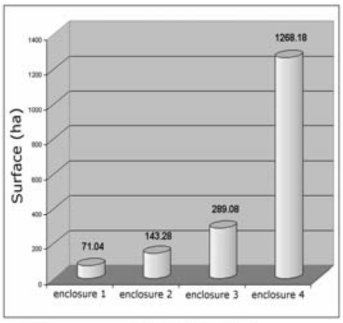
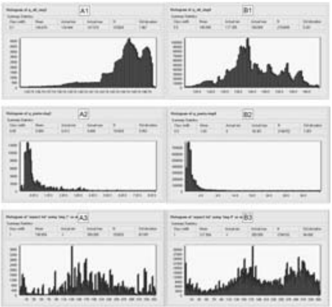


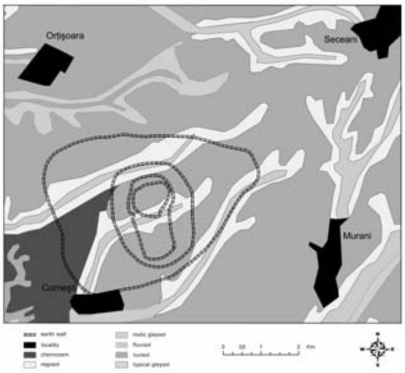
Figure 6 (left). The slope representation for the studied area. Figure 7 (right). The exposure map of the surfaces in eight directions

It is expressed in degrees starting from 0° (the North) to 360° (again North). The flat surfaces, with a 0° slope will be given the -1 value. By reclassifying the aspect values we have the map of the surface exposure (of pixels) referring to the solar radiation on eight directions (figure 7).

These can be grouped into four categories: sunlit slopes (S, SW), semi-sunlit slopes (W, SE), semi-shaded slopes (E, NE) and shaded slopes (N, NE). The map is useful for the analysis of the way in which the land was used, the distribution of vegetation and for the analysis of the distribution of the human settlements. Due to the East-West and the North-South lining of the valleys, the share of the surfaces with different orientations is appreciatively equal in the studied area. However, within the archaeological site the situation is different due to the fact that it is crossed only by valleys with a E-W lining and thus, the highest share is that of the surfaces with a N-S exposure. In the case of Enclosure 1 that extends only on the interfluves the areas with a Southern exposure are predominant due to the fact that most of it declines slightly to the South (figures 4 and 8).







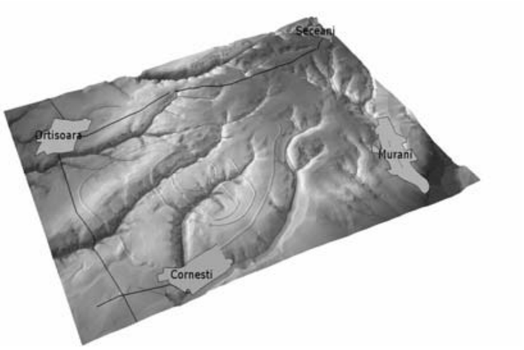


Figure 8 (upper left). The surface of each enclosure. Figure 9 (upper right). The histograms of the morphometric models for enclosures 1 and 4: A1, histogram of the altitudes in Enclosure 1; A2, histogram of the altitudes in Enclosure 1; A3 histogram of the aspect values of Enclosure 1; B1, histogram of the altitudes in Enclosure 4; B2, histogram of the altitudes in Enclosure 4; B3 histogram of the aspect values of Enclosure 4. Figure 10 (lower left). Soil map. Figure 11 (lower right). Topographic map

It is noticeable at the same time that the morphometric parameters of each enclosure, analyzed at a pixel level, although very similar, vary however according to the surface of the enclosures and their positioning on one or more interfluves (figures 4, 5 and 8). The biggest differences are between Enclosure 1 and 4.

Enclosure 1, the smallest one (71 ha), lies only on the interfluves between the Caran and Lacului rivers and has the most uniform morphometric values (table 1). The analysis of the histograms of the morphometric models (figure 9) shows that the values are closely grouped around the average. The altitude varies slightly (the amplitude is of only 12 m and the standard deviation is of 1.96) because the surface taken up by Enclosure 1 is an almost flat one (the medium slope is of only 0.96 degrees, the standard deviation = 0.95), slightly inclined towards South (figure 4).

Enclosure 4, the largest one (1268,14 ha), lies on all the three interfluves, so it presents the highest variation of the morphometric parameters (figure 6) and the highest medium altitude (145.5 m) the altitude varies a lot on the W-E lining, dropping from 168.56 m in the East to 117.35 m in the West, while on the N-S lining the variations are more reduced, from almost 160 m in the North to 130 in the South (figures 1 and 2). The amplitude of the altitude values for Enclosure 4 is of 51.21 m and the standard deviation is 9.26 (figure 9). Pedologic maps (Ianoş *et al.*, 1997) on the scale of 1:10000 were used for the making of digital maps of soils (figure 10). The maps were scanned and referenced geographically in the national coordinate system Stereo 1970. The analysis of the distribution of the types of soil reveals a clear correlation of these with the relief. As such, in the lowest S-W part there is an area taken up by chernozems, while on the other interfluves there are luvisols that take up most of the surface. The slopes of the valleys are characterized by the presence of regosols while the riversides there ale fluvisols and gleysols.

During the complex surface archaeological research our team has also made a few geophysical prospections (magnetometer) especially in the vallums and gates areas wishing to reveal the construction mode of the fortification system, and also to determine their internal chronology. The few measurements made demonstrated a complex fortification system composed of earth vallum strengthen with a double wooden stockade and defense ditch. Because of the large surface of this site and its complexity, the geophysical prospections will be continued and diversified, and will probably be the result of a future study.

As a result of the analysis of these parameters several conclusions with a geo-archaeological character can be drawn. First we can group the results of the research into two main aspects: 1 the elements of habitat, 2. the defense system. Concerning the habitat, the geomorphologic and cartographic analyses have revealed the positioning of the inhabited spaces in the areas with a S and SW exposure, within enclosures 2 and 3. Another favorable element of habitat, used by the populations located in this area, was the closeness to the water courses whose wide valleys were only slightly inclined and could be dam up and which provided the water volume necessary for a large community. The transposition of the soil types on an accurate model of the field, provides the possibility to identify the areas affected by human intervention (the habitat and plough land areas – chernozems, the old forest areas, used to maintain the fortification system – luvisols, the area of the possible lake, on the Lacului Valley, created by the dam built by the crossing of the valley by the wave of Enclosure 2 – fluvisols and gleysols).

Concerning the defense system, the analysis of the cartographic model of the land enables the drawing of preliminary conclusions referring to the positioning, the usefulness and the chronological relation among the four fortified enclosures. It can be noticed that, while enclosures 1, 2 and 3 have the role of providing intrinsic protection for the inhabited areas and the areas with a well determined function (see the case of enclosure 1 which can have an elitist/exclusive part or sacred, because up to this day no traces of habitation have been discovered), enclosure 4 has a different part, that of fencing a larger biotic space, which includes the inhabited areas and the subsistence areas (plough land, pastures, forest areas, water and fishing resources). At the same time, the lining of the 4th fortification wave has a strong military defensive character, following accurately the water-shed lines and including within it the origin of important water sources, vital to a large community that resided within this fortification.

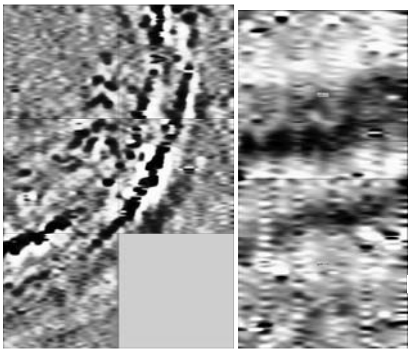


Fig. 12 and 13. Geophysical prospections (magnetometer) in earth walls no. 1 and no. 4

The situation from Corneşti "Iarcuri", in which the fortification surrounds a long existing biotic area, is a relatively rare case, which would relate to a sedentary community. It is obvious that this fortification complex is unitary and the four waves of the fortification are contemporary and do not represent the evolution steps of this community in time.

Future exhaustive archaeological digs and interdisciplinary research will complete this preliminary study based on the analysis of satellite images, aerophotograms, cartography and geomorphology of the land on which this archaeological complex is situated.

REFERENCES

Bizerea, M. 1973. Câmpia Vinga, *Studii de Geografia Banatului*, 2: 232-243

Donisă, V., Donisă, I. 1998, *Dicționar explicativ de teledetecție şi SIG.* Iaşi

Eastman, J., R. 2007, *IDRISI Andes. Guide to GIS and Image Processing.* Worcester, Masachusetts

Ianoş, Ghe., Puşcă, I., Goian, M. 1997, *Solurile Banatului*. Timişoara

Medeleț, Fl. 1993. În legătură cu fortificația de pământ de la Corneşti (comuna Orțişoara, județul Timiş), *Analele Banatului SN*, 2: 119-150

Micle, D., Măruia, L., Dorogostaisky, L. 2006. The earth works from Corneşti - "Iarcuri" (Orțişoara village, Timiş county) in the light of recent field research, *Analele Banatului SN*, 14/1: 283-305

Rada, M., Ciochină, N., Manea, D. 1989. Studiu aerofotometric al fortificațiilor de la Corneşti (jud. Timiş), *SCIVA*, 40/4: 377-380

Climate Change and Human Occupation of the Sahara

R. Blom[1], T. Farr[1], J. Feynman[1], P. Paillou[2], A. Ruzmaikin[1]

1 Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena CA 91109 USA; E-mail: ronald.blom@jpl.nasa.gov, tom.farr@jpl.nasa.gov, joan.feynman@jpl.nasa.gov, alexander.ruzmaikin@jpl.nasa.gov

2 Observatoire Aquitain des Sciences de l'Univers, UMR 5804, Floirac, France. E-mail: philippe.paillou@obs.u-bordeaux1.fr

Keywords: Sahara, human occupation, climate, solar irradiance

ABSTRACT.

Archaeology can provide insight into interactions of climate change and human activities in sensitive areas such as the Sahara, to the benefit of both disciplines. Such analyses can help set bounds on climate change projections and provide constraints on models. Details of temporal variations in the Sun, and influence of these variations on the Earth's climate, remain contentious. None-the-less, analyses of paleoclimatic data and modeling (c.f. Braconnot *et. al.*, 2007a, 2007b, 2008) indicate significant effects on human activities. The opportunity exists to more precisely constrain the relationship of natural solar and climate interactions. In our current research, we are beginning to explore the relationship of human occupation of the Sahara on long-term solar irradiance variations synergetic with atmospheric-ocean circulation patterns. The archaeological climate records for the last 12 K years are gaining adequate precision to make such comparisons possible. We employ a range of these records taken over the globe (e.g. Greenland, Cariaco Basin, and African Ocean cores) to identify the timing and spatial patterns affecting Saharan climate to compare with archaeological records. The role of radar images and other remote sensing in this work includes providing a geographically comprehensive geomorphic overview of this key area (Farr, et. al., this volume). Such coverage is becoming available from the Japanese ALOS PALSAR radar system (Paillou *et. al.*, 2007, 2008), which can guide fieldwork to collect archaeological and climatic data to further constrain the climate change chronology and link to models.

1 INTRODUCTION

The Sahara was void of settlement throughout the Last Glacial Maximum (LGM) and the terminal Pleistocene (Kuper and Kreopelin, 2006). During the early Holocene there was an abrupt arrival of monsoon rains starting ~10,500 yrs before present. This produced a savanna in the North Sahara allowing Human occupation. The Holocene period between ~9.5 and ~7 kyrs BP (calendar year before present) was the wettest phase of the last 25,000 years across much of the Levant and Eastern Mediterranean (Robinson *et al.*, 2006). Kuper and Kreopelin, (2006, see their figures 1-3) show timing of the human occupation of the Northern Sahara with data from 150 archaeological excavations in the eastern Sahara of Eygpt, Sudan, Lybia and Chad. These data show that the maximum of the human habitation in the Sahara North of 25 degrees occurred at about 7.7 kyrs BP. Insight into the role of climate change on human activities in sensitive areas such as the Sahara can help set bounds on climate change projections and provide constraints on models. In our current research, we explore dependence of human occupation in the Sahara on long-term solar irradiance variations synergetic with atmospheric-ocean circulation patterns. The Holocene paleoclimate records are gaining adequate precision to make such comparisons possible. We employ a range of these records taken over the globe (e.g. Greenland, Cariaco Basin, and West African Ocean cores) to identify the timing and spatial patterns affecting Sahara climate. Context for the regional geography and geomorphology of the human occupation record can be assessed from remote sensing data. The role of radar remote sensing in this work includes providing a geographically comprehensive geomorphic overview of this key area (Farr *et. al.*, 2008), to guide improvements in sampling and relationships of climatic indicators. Comprehensive geographic coverage is becoming available from the Japanese PALSAR radar system (Palliou, et. al., 2008), which can guide field work to collect climatic data to further constrain the climate change chronology and link to models.

2 RADAR AND OTHER REMOTE SENSING OBSERVATIONS.

That the Sahara was favorable for human habitation at times has long been known. With the remarkable paleo-landscape revealed by the L-band (25 cm) Shuttle Imaging Radar-A in 1981, it became clear that ancient humans concentrated along integrated drainage systems dubbed "radar rivers" by McCauley (*et. al.*, 1986). However SIR-A and subsequent long-wavelength radar image coverage was limited and regional understanding of the drainage network has remained elusive. A complete map of the buried channels of the region could also prove useful for development of water resources (Robinson et. al., 2006; El-Baz et. al., 2007), and understanding of past availability of this enabling resource for humans.

The Japanese ALOS (Advanced Land Observation Satellite) incorporates the PALSAR (Phased Array L-Band Synthetic Aperture Radar) L-band imaging radar. Launched in January 2006, data from the satellite is increasingly being applied to a variety of disciplines (http://alos.jaxa.jp.main2e.html). Paillou, et. al., (2008) report on progress on creation of an ALOS L-Band SAR image mosaic being assembled for North Africa. A key goal of this project is to create a database for study of the paleohydrology of the region. Farr (et. al., 2008, also this volume) report on preliminary results of study of the Gilf Kebir region. The resulting geo-referenced image data set will provide the regional context to analyze the timings and locations of human occupation reported by Kuper and Kreopelin, and compare with the climate modeling.

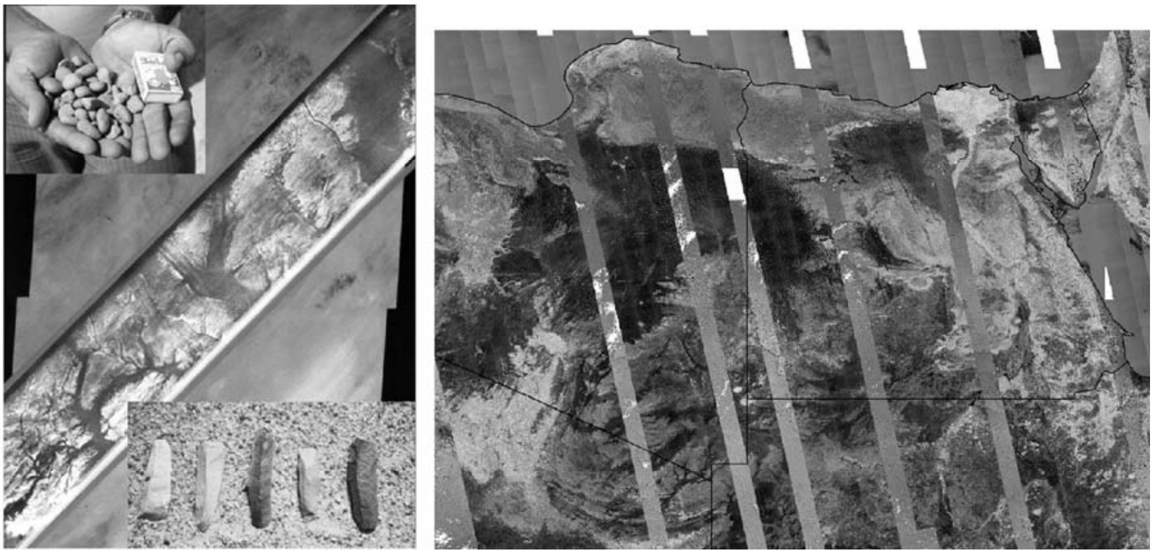


Figure 1. A-left) Western Desert of Egypt, SIR-A image overlain on Landsat MSS image of same area showing dramatic expression of fluvial features now hidden under shallow sand cover. Insets show rounded pebbles and Neolithic artefacts found at "radar rivers". B-right) SRTM C-band radar image with in progress PALSAR image mosaic overlain for Egypt, Sudan, and Gaza. See Farr, et. al., 2008, and this volume, and also Paillou, et. al., 2007, 2008 for more discussion.

3 SOLAR IRRADIANCE, MODELING, AND CLIMATE CHANGE.

Soon after the discovery of the Green Sahara it was suggested that this important and clear example of climate change was basically due to the changes in the position of the monsoon belt over the Sahara brought about by changes in the Earth's orbit relative to the Sun. The monsoon belt is associated with the Intertropical Convergence Zone (ITCZ). Over land, the ITCZ moves back and forth across the equator following the sun's zenith point. It is thus modulated by changes in the Earth's position relative to the Sun, i.e. by the Milankovich cycles. In addition there are other influences on the position, in particular the gradient of the sea surface temperature. Over the oceans, where the ITCZ is better defined, the seasonal cycle is more subtle, as the convection is constrained by the distribution of ocean temperatures. A quasi-linear relation has been found between the monsoon precipitation in Africa and the summer insolation integrated over the Northern Hemisphere (Prell and Kutzbach, 1987). Recently GCMs containing interactive atmosphere, ocean, land surface and sea ice have become remarkably successful in simulating Saharan climate for the Early Holocene (9.5 kyr) and the Mid- Holocene (6.0 kyr) (Liu *et al.*, 2007; Braconnot *et al.*, 2007b). The simulations demonstrate changes in the position of the monsoon belt that brought rain to the Sahara at those times. However, no modeling or simulations have been carried out to explain the timing of the maximum human occupation of the Green Sahara (MGS) at about 7.7 kyrs BP.

PMIP (Paleoclimate Modeling Intercomparison Project) model experiments reported by Braconnot et. al., (2007a, b, 2008) show that the differences between Eastern North Africa during the early Holocene (EH) at 9.5 kyr BP and the Mid Holocene (MH) at 6.0 kyr BP are quite well simulated using the coupled interactive models with the parameters of the Earth's orbit (eccentricity, obliquity and precession) as initial conditions. The estimate of the climate of the Earth produced from these advanced PMIP experiments depends almost entirely on the parameters of the Earth's orbit chosen at the time to be investigated (Renssen et. al., 2006). The simulations using interacting models of the atmosphere, the ocean, land surface and sea ice show feedbacks from the ocean tend to amplify the strengthening of the African Monsoon induced by the insolation. The precession is important because it modulates the length of the season and the time during the summer when insolation is maximized. The estimate of the orbital parameters for the GSOM from those for the EH and MH shows that the most important change is that the obliquity of the orbit, which modulates the latitude of the summer solstice. The position of the monsoon is also effected by the latitudinal gradient of the sea surface temperatures (SST). We are looking at the Holocene SST data sets taken in North Atlantic.

Ocean sediment cores from the Cariaco basin have been used (Peterson & Haug, 2006) to estimate the position of the ITCZ and hence the monsoon belt position as a function of time throughout the Holocene. The changes in the position at the relevant times are quite complex, and seem to combine the extreme in obliquity with the effect of the changes in ocean circulation brought about by the 8.2 kyr BP event. The Cariaco data from Venezuela are well-correlated with data taken off the coast of Africa (deMenocal et. al., 2000). Figure 2 shows both sets of the data and their joint probability with respect to temperature. The data are anti-correlated (the correlation coefficient between these two data sets is about 0.57). The two maxima in their joint probability density function correspond to periods of the wet (right maximum) and dry Sahara (left maximum).

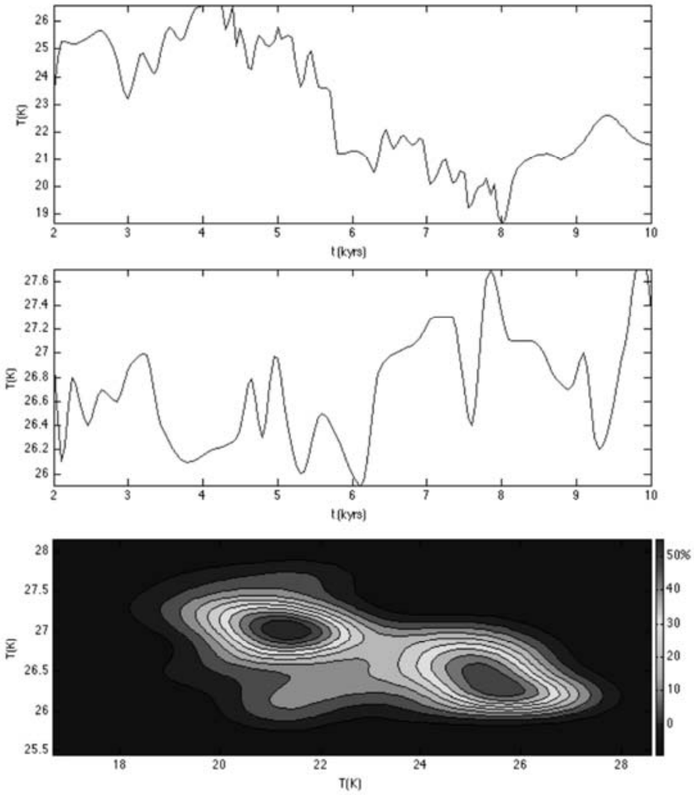


Figure 2. Cariaco Venezuela, temperature retrieval (top, data used are from Lea, D.W., et. al., 2003), compared to Africa temperature retrieval (middle, data used are from deMenocal, et. al., 2001) from 10K years ago to 2K years ago. Bottom figure illustrates the relationship by showing calculated joint probability density function over time. The left maximum corresponds to a dry Sahara, while the right corresponds to a wet Sahara.

4 SUMMARY

The paleogeography revealed in the radar images is to be compared with the temporal changes in climate indicated by data and modeling. The georeferenced image data set will provide the regional context to analyze the timings and locations of human occupation reported by Kuper and Kreopelin, and compare with the climate modeling. Expected results include an improved understanding of the relationship between various climatic forcing functions and responses, and a better understanding of the relationship between humans and their changing environment during the Green Sahara phase.

5 ACKNOWLEDGEMENTS

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA), and funded through NASA's

Earth Surface and Interior Program and also the JPL internal Research and Technology Development (R&TD) program. Paillou's research supported by CNES. PALSAR data graciously supplied by JAXA.

6 REFERENCES:

Braconnot, P., et. al., 2007a, Results of PIMP2 coupled simulation of the Mid-Holocene and Last Glacial Maximum-Part 1: experiments and large-scale features: Clim. Past, 3, p. 261-277.

Braconnot, P., et. al., 2007b, Results of PIMP2 coupled simulation of the Mid-Holocene and Last Glacial Maximum-Part 2: feedbacks with emphasis on the location of the ITCZ and mid-and high latitudes heat budget: Clim. Past, 3, p. 279-296.

Braconnot, P., Marzin, L. , Gregoire, E. , Mosquet, E. , Marti, O. 2008. Monsoon response to changes in Earth's orbital parameters: comparisons between simulations of the Eemian and of the Holocene: Clim. Past Discuss., 4, p. 459-493.

deMenocal, P., Ortiz, J., Sarnthein, M. 2000. Coherent High- and Low-Latitude Climate Variability During the Holocene Warm Period: Science, 288 (5474): 2198.

El-Baz, F., Robinson, C.A., Al-Saud, T.S.M. 2007. Radar images and geoarchaeology of the eastern Sahara, ch. 2 in *"Applications of Remote Sensing to Archaeology",* El Baz, F., and Wiseman, J. eds., Springer, ISBN 978-0387444536.

Farr, T. G., Blom, R. G., Paillou, Ph.. 2008. Hydrologic history of the eastern Sahara from imaging radar: Proc. IEEE IGARSS 2008 Conf. July 6-11, 2008 Boston MA. http://igarss08.com/

Kuper, R., Kröpelin, S. 2006. Climate-controlled Holocene Occupation in the Sahara: Motor of Africa's Evolution, Science 11 august 2006, vol 313, #5788, p. 803-807 DOI 10.1126/science.1130989.

Lea, D.W., et al., 2003 Cariaco Basin Foraminiferal Mg/Ca and SST Reconstruction, IGBP PAGES/World Data Center for Paleoclimatology NOAA/NGDC Paleoclimatology Program.

Liu, Z., et. al., 2007, Simulating the transient evolution and abrupt change of Northern Africa atmosphere–ocean–terrestrial ecosystem in the Holocene, Quaternary Science Reviews 26 1818–1837.

McCauley, J.F., Breed, C.S., Schaber, G.G., McHugh, W.P., Issawi, B., Haynes, C.V., Grolier, M.J., El Kilani, A. 1986. Paleodrainages of the eastern Sahara- the radar rivers revisited (SIR-A/B implications for a mid-Tertiary trans-African drainage system), *IEEE Trans. Geosci. Rem. Sens.*, v. GE-24 : 624-648.

Paillou, Ph., Lopez, S., Lasne, Y., Rosenqvist, A. , Farr, T. 2007. Mapping subsurface geology in arid Africa using L-Band SAR, *Proc. IEEE IGARSS*, doi: 10.1109/IGARSS.2007.4423396.

Paillou, Ph., Farr, T. G., Rosenqvist, A. , Lopez, S. 2008. A PALSAR mosaic of Sahara to map subsurface geology, IGARSS '08, session on Mapping Subsurface Geology. http://igarss08.com/

Peterson, L. C., Haug, G. H. 2006. Variation of the mean latitude of the Atlantic Intertropical Convergence zone as recorded by riverine input of sediments to the Cariaco Basin Venezuela, *Palaeogeographical, Palaeoclimatological, Palaeoecological*, 234 : 97-113, doi:10.1016/j.palaeo.2005.10.021.

Prell, W. L., Kutzbach, J. E. 1997. Monsoon variability over the past 150,000 years, *J. Geophys. Res*. 92 :8411-8425.

Renssen, H., Driesschaert, E., Loutre, M. F., Fichefet, T. 2006. On the Importance of initial conditions for simulations of the Mid-Holocene Climate, *Clim. Past*, 2 : 91-97.

Robinson, C., El-Baz, F., Al-Saud, T.S.M., Jeon, S.B. 2006. Use of radar data to delineate paleodrainage leading to the Kufra Oasis in the eastern Sahara, *J. African Earth Sci*., 44 : 229-240.

Archaeological landscape of the Don River Delta: archaeology, remote sensing and GIS

G. Garbuzov, I. Tolochko

Southern Scientific Centre of the Russian Academy of Sciences, 41, Tchehova Str., Rostov-na-Donu 344006 Russia, garbuz.g@gmail.com, ivtolochko@mmbi.krinc.ru

Keywords: landscape archaeology, cultural heritage management, archaeological modelling, GIS, remote sensing

ABSTRACT.

The region of the Don (Greek *Tanais*) river delta is one of the most intensively inhabited among other regions of the Northern Black Sea coast. The area of the Lower Don enclosing delta part was a unique contact zone between different ethno-cultural traditions and civilizations during many millenniums. There are numerous archaeological sites in this relatively small zone (about 450 sq. km) from Paleolithic to the Middle Ages. The bulk of the archaeological sites located in the Don delta especially settlements has the complex multilayered character. Now there are the significant fast changes in the Lower Don area caused by intensive growth of both industrial and agriculture production accompanied expansion of modern settlements with general increase of anthropogenic impact on the traditional landscapes. These uncontrollable processes cause serious damages to archaeological heritage and to common cultural originality of the Don delta. It is the strong reason for exact revaluation of local archaeological potential the more so because it is revealed now presumably just around 20-25% from total possible number of archaeological sites. In this connection the first-priority aim of the presented Don delta archaeological project is a development of optimal strategy to reveal a complex archaeological landscape of the Don delta as full as possible. It is implied suitable prospection methodology, complete data sets and advanced analytical tools.

From the methodological point of view the region of the Don delta gives an exceptional opportunity for using and developing a wide range of technological instruments relating to non-destructive archaeology and archaeological geoinformatics. Generally on an example of this test area we are able to develop the systematic approach to the archaeological researches based on the geospatial analysis of revealed archaeological records and environment variables within uniform archaeological GIS. The primary spatial data have been formed by results of geophysical, geochemical (soil) and archaeological field surveys connected with remote sensing data. Latter data block helps to carry out the landscape analysis to provide us with important information on geomorphology like a spatial/temporal variability of the channel network. Archaeological predictive model taken into account the land dynamics during delta evolution is one of the main aims of GIS applications. Another planned task is a modeling of regional settlement patterns associated with various types of human activities. In a number of consistently replaced archaeological cultures, behavior types and land use the greatest attention is paid to antique age (IV c. B. C. – III c. A.D.) which is especially interesting significant interaction of the western civilization presented in the Don delta by large antique centers (*Tanais* and Elizavetovskoe settlement) with extensive system of antique rural sites, and outside civilizations of the Eurasian steppes. Presented archaeological project has universal character and it makes possible resolution of the problems concerning both academic research and cultural resource management

Lower basins of all rivers on northern coast of Black Sea (Dnieper, Don, Kuban) were the regions of intensive civilizations processes in antiquity. Greek colonization of the region started from there at VII/VI centuries BC and continued at V and III BC. *Borysthenes* and *Olbia* have been founded at Dnieper delta, *Phanagoria, Hermonassa, Patreaous, Gorgipia* on low Kuban river, Taganrog settlement, Elizavetovskoe settlement and finally *Tanais* appeared in the Don delta. From last relatively small region (450 sq. km) came over 50 known archaeological sites dated from Paleolithic to Middle Ages. A border between nomad (from the Step) and settled populations (along rivers sides) have been formed at very early times existed there for many centuries. Most of the settlements (Elizavetovskoe, Tanais, Asak/Tana) have been in the same time a points of intensive trade exchanges and “pots for melting” of different ethnic populations – Greeks, Scythians, Sarmathians, Goths, Huns, Alans and Khazars tribes.

Landscape of the Don delta (figure 1) is different from a wide, rather flat meadows in the neighborhood and conditions there were favorable not only for fishing and hunting but also for agriculture and pasture. It is a reason of intensive settlement processes - most of the known archaeological sites has multi-strata character and has been connected with many different archaeological cultures. However, it is rather difficult to study detected features in their original archaeological landscape (it is calculated that only 20-25% of possible sites have been discovered) thought archaeological excavations have been carried out there from XIX century (Leont’ev, 1854) and intensive field walking surveys have taken place both at the beginning (Miller 1910; 1925) and at the end of XX century (Marčenko, 1995; Marčenko *et al.*, 2000).

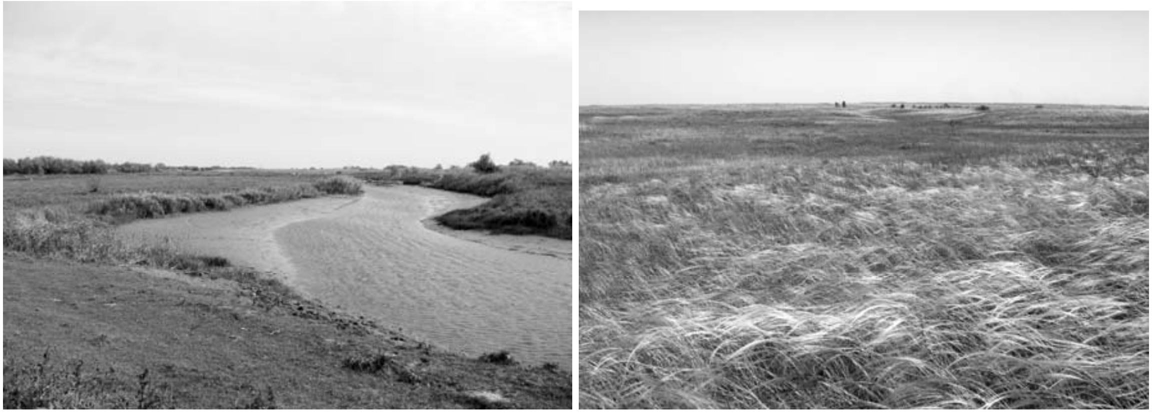


Figure 1. Don river delta landscapes: small channel(Kabačnyj Erik) in the west part of delta and area of sand dunes in the central part of delta with feather grass association

Central and western part of region have been intensively studied (small trial excavations included) from 1950 to 1980 (Gvozdover, 1959; Boriskovskij & Praslov 1964; Praslov 1968; Brašinskij & Marčenko 1972; Šelov 1972; Kruglikova 1974; Čalyj & Zavgorodnij, 1983; Gudimenko & Maslovskij, 1994; Schultz,e 2005) but most of the discoveries (Laguntik, Bugry, Kažačij Erik, Rogožkino) have published only in a form of short field reports (Gadlo, 1964; Gudimenko, 1991; 1993; Bezuglov & Gudimenko, 1993; Potapov 2004; Maslovskij 2006). Also small finds (collection of over 12 000 exemplars) stored at the Archeological Museum at Azov have been only primary studied, classified and published. Additionally there were a lot of changes in landscape during last decades resulting from industrialization, melioration any many other kinds human activity. A lot of archaeological sites have been destroyed in this period. Situation has been changed at 2005 when a nature reserve park was created in central and western parts of the Don delta. It is critically important as just in the central part of delta are concentrated most of known archaeological sites. Natural landscape of this part of the region are formed with areas of sand dunes laying 3-4 meters over the sea level (sometimes over 6 meters) cut by small shrink rives and former riverbeds. Supposed that dune areas were produced by erosion of paleo-Don terrace (Rodionov, 1958).

There is extremely difficult to obtain good result of field walking survey in such geological conditions. From already made surveys it is clear that most of the archaeological sites should be situated in the highest parts of the dunes but in the same time there are covered by sand and practically any kind of archaeological material is present on the surface. Even if we find some fragments of pottery, stones, metal or other small finds its archaeological context is unclear. It is practically impossible to find the limits of site and concentrations of possible archaeological objects only by field walking. This kind of activity must be connected with core sampling technique in the places calculated with the use of statistic methods (Hoffman 1993), geophysical surveys, pollen analysis etc. The best examples of such a work done in similar conditions come from Netherlands (Peeters, 2007; Verhagen, 2007) and many of experiences of our Dutch colleges can be adopted to our work.

One of the most useful and powerful method adopted to the reconstruction of archaeological landscape of Don river delta is the remote sensing with the use of satellite and airborne images analysis. All information coming from these analysis are transformed to the data base accepted by GIS system. Remote sensing image itself can be use to plot the results of field surveys. As example we made such figure based on high quality Ikonos/GeoEye space image from Google internet portal (fig. 2).

Data from core sampling are also one of the most important elements of GIS analysis. This can be basis for reconstructions of all changes both natural and anthropogenic at Don river delta having place form Paleolithic to modern times. Predictive models of these kinds of changes (Peeters, 2007) can be prepared for all delta (in general) and also as detailed information concerned each part of landscapes close to detected archaeological sites (treated separately). One of the most important result of the comparative analysis is the observation of differences in landscape existed around Greek settlement at Elizavetovskoe in early Hellenistic time and close to Greek colony of *Tanais* in Late Antique.

The project presented here (started at 2007) is on a fist stage of realization. However already obtained results allow to form new hypothesis, that can change radically our knowledge concerning history of Greeks activity on northern coast of the Black Sea in Hellenistic times. It can be also used as a base of the most of the project prepared with the aim of heritage and natural landscapes protection.

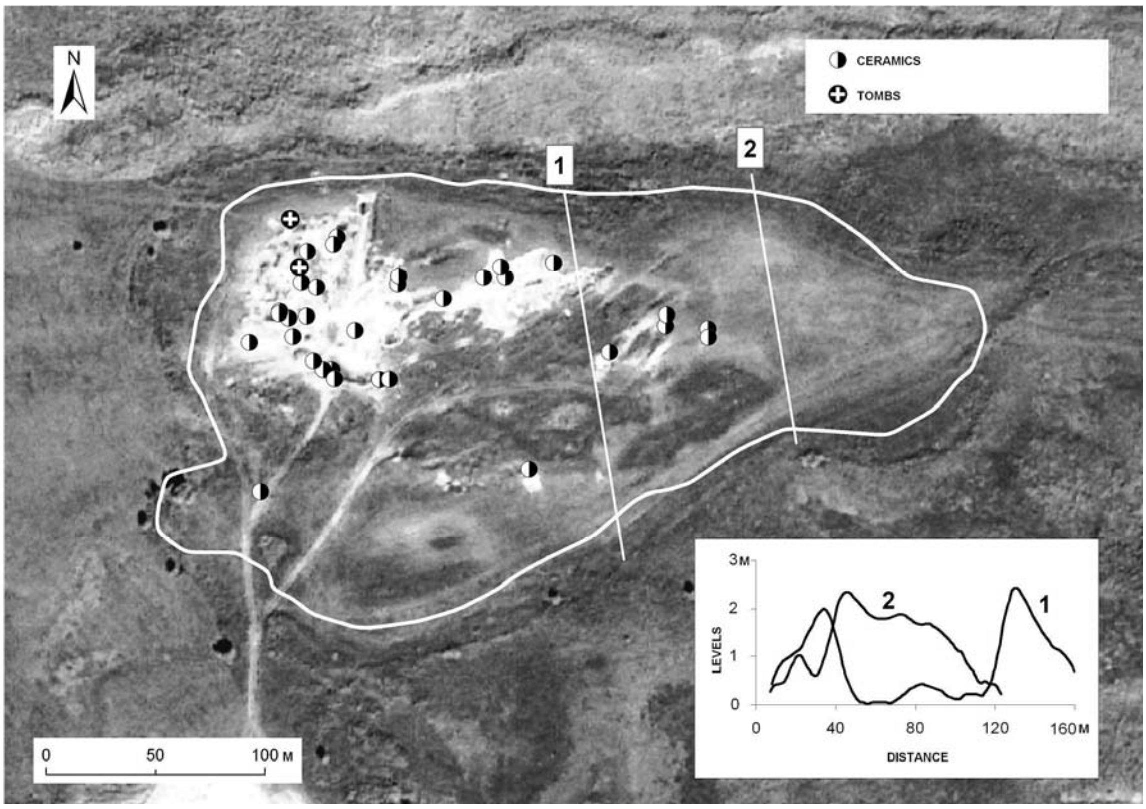


Figure 2. Ikonos/GeoEye satellite image (27 Sept. 2006) from Google internet portal used for site Rogožkino XI location. 1 and 2 - lines of vertical profiles

REFERENCES

Bezuglov, S.I., Gudimenko, I.V. 1993. Podveska s vyemčatoj emaliu iz delty Dona. *Rossijskaja archeologija* 1: 169-174.

Boriskovskij, P.I., Praslov, N.D. 1964. Paleolit bassejna Dnepra i Nižnego Dona. *Svod archeologičeskich istočnikov* A1–5: 67–92.

Brašinskij, I.B., Marčenko, K.K. 1972. Raskopki i razvedki v delte Dona. *Archeologičeskie otkrytija 1971 g.*: 68–69.

Čalyj, V.V., Zavgorodnij, A.M. 1983. Archeologičesskie issledovanija v delte Dona. *Issledovanija Azovo-Doneckoj archeologičeskoj ekspedicii v 1983 g.* Azov: 10–12.

Gadlo A.V. 1964. Poselenie XI-XII vv. v delte Dona. *Kratkie soobščnija instituta archeologii* 99: 40-45.

Gudimenko, I.V. 1991. Fibuly III – IV vv. n.e. s pozdneantičnych poselenij delty Dona. *Istoriko-archeologičeskije issledovanija v Azove i na Nižnem Donu v 1990 godu* 10. Azov: 96–103.

Gudimenko, I.V. 1993. Nekropol' pozdneantičnogo poselenija Rogožkino-XIII. *Istoriko-archeologičeskije issledovanija v Azove i na Nižnem Donu v 1991 godu* 11. Azov: 104-121.

Gudimenko, I.V., Maslovskij, A.N. 1994. Razvedki v Azovskom rajone. *Istoriko-archeologičeskije issledovanija v Azove i na Nižnem Donu v 1993 godu* 13. Azov: 26.

Gvozdover, M.D. 1959. Razvedki paleolita na Nižnem Donu. *Izvestija Rostovskogo oblastnogo muzeja kraevedenija* 1(3): 20–34.

Hoffman, C. 1993. Close-interval Core Sampling: Tests of a Method for Predicting Internal Site Structure. *Journal of Field Archaeology* 20: 461-473.

Kruglikova, I.T. 1974. Raboty Sucho-Čaltyrskogo otrjada Nižne-Donskoj ekspedicii. *Archeologičeskie pamjatniki Nižnego Podonja* II: 175–185.

Leont'ev, P.M. 1854. Archeologičeskie razyskanija na meste drevnego Tanaisa i v ego okrestnostjach. *Propilei* IV.

Marčenko, K.K. 1995. Ekologičeskaja situacija i kulturogenez v severo-vostočnom Priazovie – Nižnem Podon'e skifskoj epochi. *Vestnik drevnej istorii* 4: 96–105.

Marčenko, K.K., Žitnikov, V.G., Kopylov, V.P. 2000. *Die Siedlung Elizavetovka am Don*. Pontus Septentrionalis II. Tanais 2. Moskau.

Maslovskij, A.N. 2006. Archeologičeskie issledovanija v Azove i Azovskom rajone v 2005 godu. *Istoriko-archeologičeskije issledovanija v Azove i na Nižnem Donu* 22. Azov: 102–126.

Miller, A.A. 1910. Raskopki v rajone drevnego Tanaisa. *Izvestija Archeologičeskoj Komissii 35:* 86–130.

Miller, A.A. 1925. Kratkij otčiot o rabotach Severo-Kavkazskoj Ekspedicii Akademii v 1923 g. *Izvestija Gosudarstvennoj Akademii Istorii Material'noj Kultury* IV: 1–42.

Peeters, J.H.M. 2007. *Hoge Vaart-A27 in context: Towards a model of Mesolithic - Neolithic land use dynamics as a framework for archaeological heritage management*. Amersfoort, Rijksdienst voor Archeologie, Cultuurlandschap en Monumenten.

Potapov, V.V. 2004. Raskopki v delte Dona. *Istoriko-archeologičeskije issledovanija v Azove i na Nižnem Donu* 20. Azov: 126–127.

Praslov, N.D. 1968. Rannij paleolit Severo-Vostočnogo Priazovja i Nižnego Dona. *Materialy i issledovanija po archeologii* 157: 78–99.

Rodionov, N.A. 1958. *Gidrologija ust'evoj oblasti Dona*. Moskva.

Schultze, E. 2005. Das Dondelta in römischer Zeit – Stand der Forschungen zum direkten Umfeld der antiken Stadt Tanais. *Eurasia antiqua* 11: 205-230.

Šelov, D.B. 1972. *Tanais i Nižnij Don v pervye veka našej ery*. Moskva.

Verhagen, P. 2007. *Case studies in archaeological predictive modelling*. Leiden University Press.

Irrigation is Forever: a study of the post-destruction movement of water across the ancient site of Sri Ksetra, Central Burma.

J. Stargardt[1], G. Amable[2], B. Devereux[2]

1 Department of Geography and Sidney Sussex College, University of Cambridge, Cambridge CB2 3HU, U.K. E-mail: js119@cam.ac.uk
2 Unit for Landscape Modelling, Department of Geography, University of Cambridge, Cambridge CB2 1QB, U.K. E-mail: gsa1000@cam.ac.uk

Keywords: multi-temporal and multi-spectral satellite imagery; Burmese urban archaeological site; ancient irrigation; enduring effects; modern landscape

ABSTRACT

This paper is a study in the movement of moisture after the end of the monsoon season, i.e. in November and December, across the large urban archaeological site of Sri Ksetra in Central Burma. It is based on the study of combined resources, including high resolution, space-borne multi-spectral and multi-temporal satellite imagery, aerial photographs and archaeological maps. This study contributes to the understanding of surface and sub-surface water flows in the ancient irrigation system of the site, discovered by Stargardt in 1988 and first published in 1990. That system has been in disrepair for a thousand years, yet still functions at a subsurface level, creating differences in soil productivity and drainage today. The study also explores the potential value of such imagery for other archaeological research on the ancient landscapes embedded in modern ones.

1 INTRODUCTION

Sri Ksetra is one of the oldest and largest urban sites in Southeast Asia. The site is located in the eastern part of the Irrawaddi basin in central Burma (figure 1). Archaeological research began there in 1904 and continues up to the present in spite of the impediments posed by current conditions in Burma. Located in the zone of transition between the heavy rainfall coastal belt of Burma and the large Dry Zone of the central area, Sri Ksetra relied heavily on water harvesting and distribution after the end of the rainy season to support rice cultivation and supplementary field and garden crops. That it succeeded in doing so is demonstrated by the longevity of the city and its associated area, c. 4th - 9th century AD, and by their flourishing Buddhist culture. Sri Ksetra was the largest city created by the Pyu civilization of Burma, a Tibeto-Burman speaking population who had their own highly articulated religious system involving the cremation of the dead and their burial in urns in close proximity to the living. With the widespread adoption of Buddhism and many contacts with the rich Buddhist cultures of Andhra (South-East India) in the 4th-5th century, they assimilated their mortuary customs into Buddhist monumental complexes. Although foreign coins and artefacts have been found in the city, the main foundations of its prosperity lay in its irrigated agriculture rather than in its trade.

The enclosed city extends over more than c. 17 sq km inside the outer walls. With an additional extramural area, a surface area of at least 36 sq km of land were delineated by a continuous irrigation system serving agriculture, horticulture and urban clusters of monuments, burials and habitations both inside and outside the walls. As a result of its extended format, this site differed sharply from the compact ancient urban settlements of Europe and the Near East, but represents a type of ancient royal city found frequently in South, Southeast and East Asia. Whereas in South and East Asia the culturally and economically significant zones of ancient urban space were typically demarcated by walls and pathways, in the royal cities of Southeast Asia, this role was traditionally (and to an extent still is) played by man-made bodies of water in the form of moats, canals, ponds and larger tanks. This underscores the importance placed by these royal kingdoms on the effective control, harvesting and efficient use of ground and surface water resources.

The present day landscape supports a mixture of land uses, dominated by agriculture and residential uses. The western parts of Sri Ksetra now support residential extensions of the nearby city of Pyay (erroneously spelt Pye on some modern maps). Regrettably many of the historic man-made water-bearing structures have been left in a state of disrepair for centuries and most are no longer visible on the ground. In this paper we present the results of a satellite remote sensing study of the role of these early historic structures in the present-day landscape. We examine their impact on the spatial and temporal patterns of surface and ground water resources in the landscape.

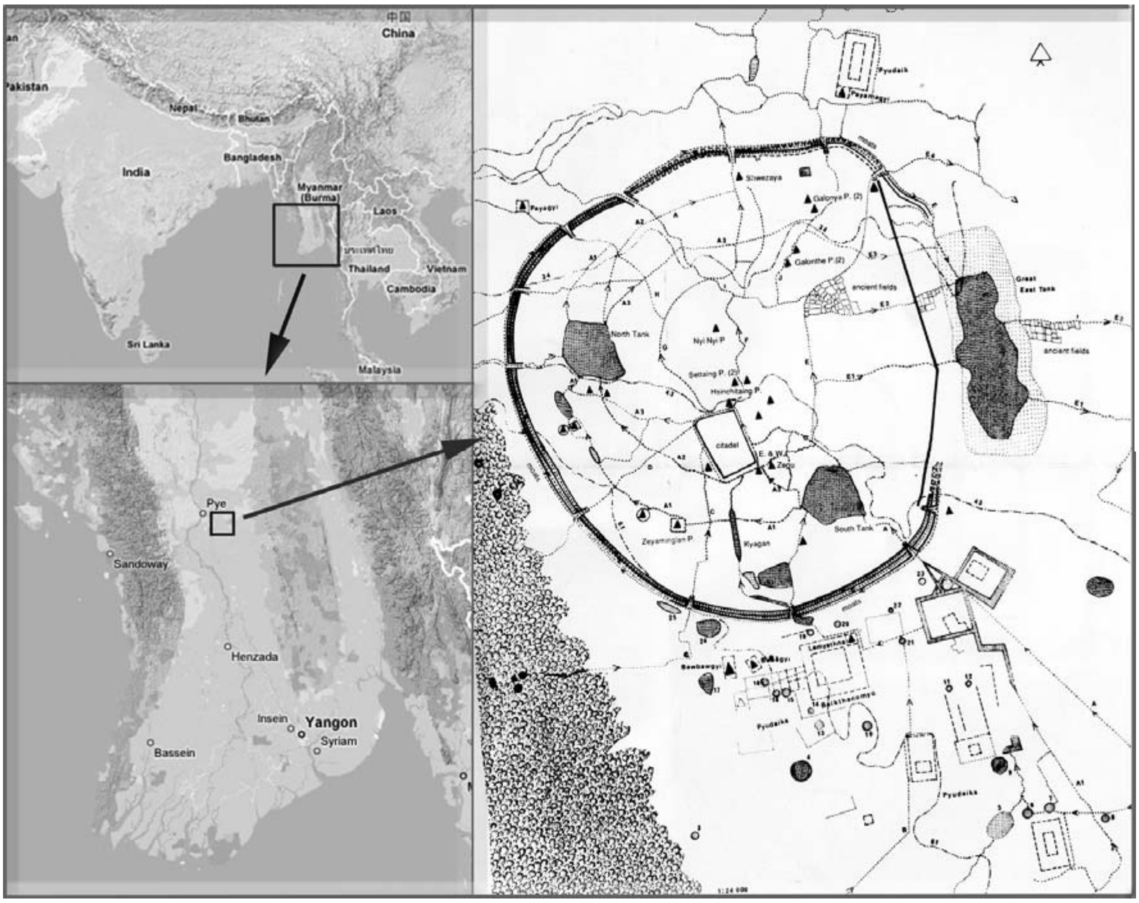


Figure 1: Location and detailed archaeology of the ancient city of Sri Ksetra, Central Burma. (Sources: main map: Stargardt (1990); coloured location maps: Google Earth (2008).

2 DATA AND METHODS

High-resolution digital elevation data of the kind used in recent mapping of surface archaeology at UK and European sites (see for example, Devereux *et al.,* 2005; 2008; Bewley *et al.,* 2005 and Doneus & Brisse, 2006) are not yet available for the Sri Ksetra site. However, detailed archeological mapping of the site was compiled in the late 1980s by Stargardt (see examples published in Stargardt, 1990 and Stargardt, 2001a) using a combination of air photos flown by the Royal Air Force (RAF) in 1953 and surface checking. This map served as the baseline data for this present study (an extract is shown in figure 1). Additionally, we used uncontrolled air photo mosaic created from the RAF imagery (figure 2a) and two recent multispectral LANDSAT ETM images acquired from the Global Land Cover Facility (NASA Landsat Program, 2004). The first of the two ETM images was collected in mid-November (just after the rainy season) and the other in late December (the early part of the dry season). These allowed the study of the spatial patterns and dynamics of surface and ground water regimes.

Prior to detailed interpretation, the ETM images were pan-sharpened, a spatial enhancement technique which involves the use of the 15m panchromatic band to enhance the resolution of the visible and near infrared bands (King & Wang, 2001). At 15m spatial resolution, the resulting multi-spectral images are sharper and portray more vivid landscape details.

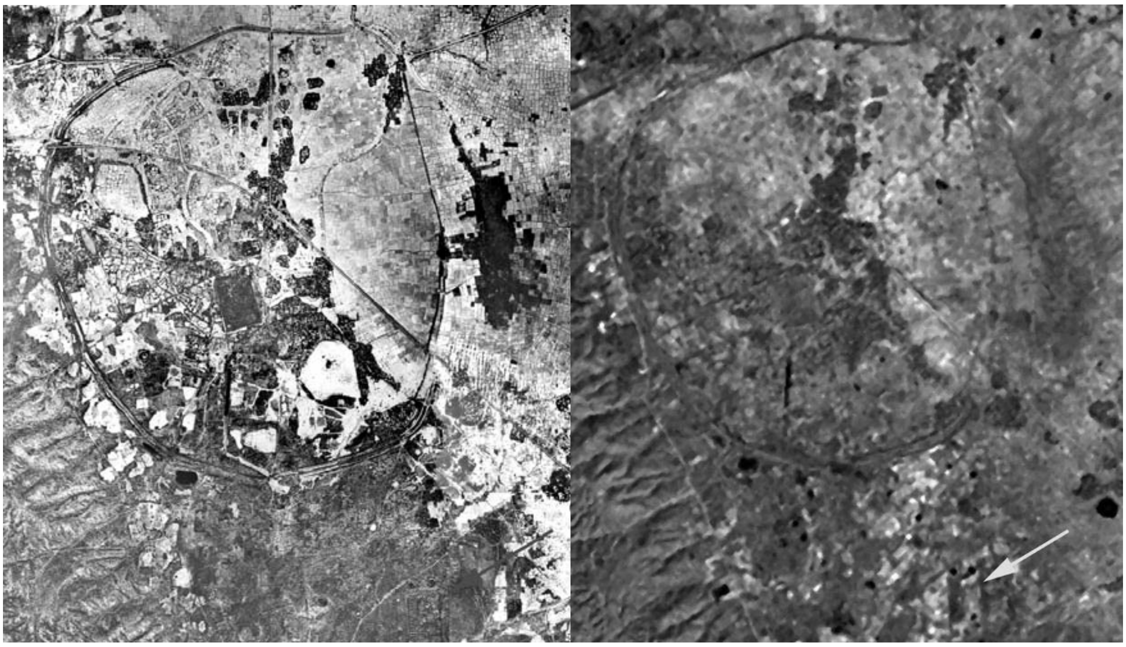


Figure 2: (a) Air photo mosaic compiled from RAF aerial survey of 1953; (b) Pan-sharpened infrared colour composite of LANDSAT ETM acquired in December 1999. The dark features in the infrared image are open water features. Rectangular-shaped burial compounds can be seen in the south; they are rectangular enclosures with two circular burial pools at one end (example arrowed).

A number of indices have been proposed for the mapping of open water features and vegetation water content from spectral images. One of the commonest of these is the Normalised Difference Water Index (NDWI) which uses the green and short-wave infrared spectra (McFeeters, 1996) Modified versions have also been also been proposed (see for example Ouma and Tateishi, 2006 & Xu, 2006). We computed NDWIs for the two data sets using ETM Bands 2 (green) and 5 (NIR). We also employed the Tasseled Cap wetness (TCW) component (Huang, 2002) and the commonly used Normalised Difference Vegetation Index (NDVI) to examine the general patterns of vegetation development and vegetation wetness and greenness. Multi-temporal comparisons of these indices were used to show the spatial and temporal patterns of water movement at the Sri Ksetra site.

3 RESULTS AND DISCUSSIONS

The NDWI for the two dates are shown in figures 3a and b. The indices show a clear pattern of ground water movement across the site. As expected the general pattern of water movement through the season follows the general slope of the landscape from the ridge in the southwest to the eastern and northeast directions. The TCW components also show the same patterns. In addition to showing surface water features, the NDWI and TCW for the two dates clearly portray the strong differential patterns of water retention, at a sub-surface level, at the sites of the c.1400-year old irrigation structures (consisting of moats, canals and tanks, cf. figures 1, 3a and b) despite the fact that many of these structures and water-bodies are no longer visible on the surface today. Conversely, the recent assertion by Hudson (2007) that the wide water course running across the site SW to NE, through or under the palace area is part of the ancient system is not supported by the evidence of these images. It may be considered to have resulted from later erosion.

The spatial and temporal patterns of the NDVI, a reflection of the development of photosynthetically active vegetation at the site and through this part of the season, also portray the differential pattern of moisture availability and moisture use by vegetation. These patterns further confirm the active influence of the ancient hydraulic structures on the landscape at a sub-surface level. The site of the east tank, which the locals still refer to as 'the ocean', appears to be a rich, sub-surface moisture pool in the dry seasons, which cannot be detected in surface checking now but was certainly a major feature in the past. Many royal cities in South East Asia were shaped by water to represent microcosms of great symbolic importance, demonstrating royal power and its special links with the cosmos.

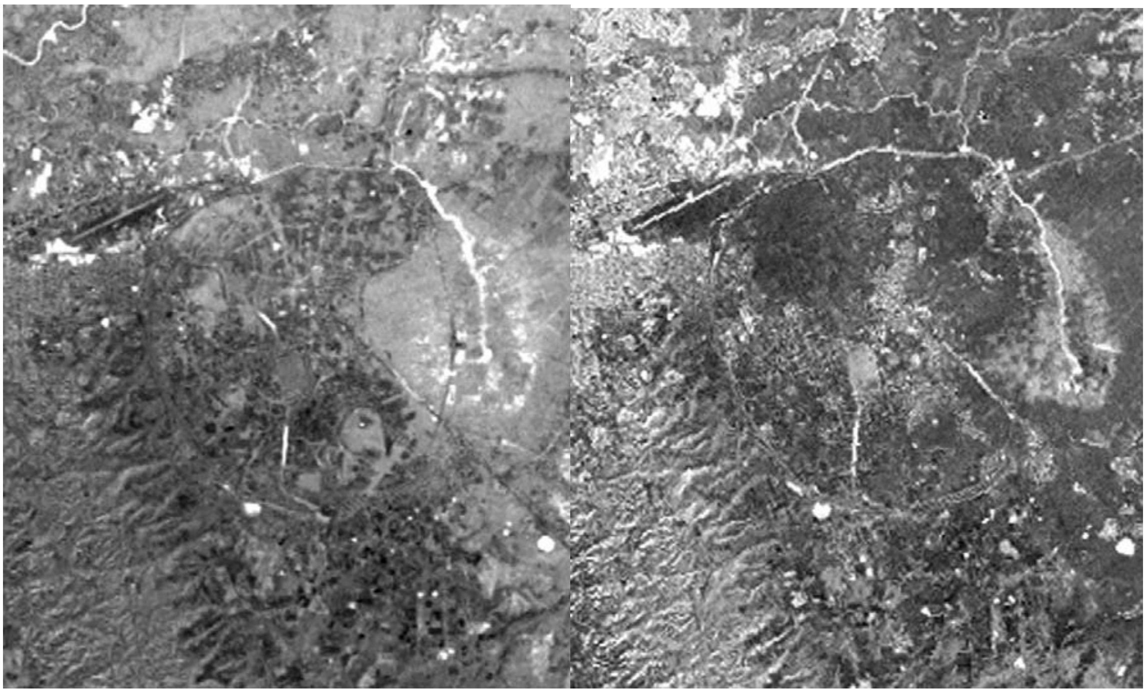


Figure 3: Normalised Difference Water Index (NDWI) at Sri Ksetra for mid-November (a) and late December (b). Lighter shades indicate surface water or areas of high moisture content.

Even when realised only to a limited extent, such sacred urban geographies were easily recognised by their inhabitants and travellers. Microcosms delineated by water can still be seen beneath the incrustations of modernity in Bangkok and Phnom Penh and with much greater clarity at sites such as Sri Ksetra and Angkor. As we have shown above for Sri Ksetra, the impact of these on modern landscapes can be detected from multi-spectral remotely sensed imagery and derived indices. Thus the water movements traced in this paper originally performed symbolic as well as practical functions at Sri Ksetra.

4 REFERENCES

Bewley, R.H., Crutchley, S., Shell C. 2005. New light on an ancient landscape: LiDAR survey in the Stonehenge World Heritage Site. *Antiquity* 79: 636-47.

Devereux, B.J., Amable, G., Crow, P., Cliff. A. 2005. The potential of airborne LiDAR for detection of archaeological features under woodland canopies. *Antiquity,* 79: 660.

Devereux, B.J., Amable, G., Crow, P. 2008. Visualisation of LiDAR terrain models for archaeological feature detection. *Antiquity,* 82: 470–479.

Doneus, M., Briese, C. 2006. Full-waveform airborne laser scanning as a tool for archaeological reconnaissance. In: Campana S., Forte M. (eds.), *From Space to Place. Proceedings of the 2nd International Conference on Remote Sensing in Archaeology.* BAR International Series 1568: 99-106.

Huang, C., Wylie, B., Yang, L., Homer, C., Zylstra, G., 2002. Derivation of a tasselled cap transformation based on Landsat 7 at-satellite reflectance. *Int. J. Remote Sensing*, 23(8): 1741 - 1748.

Hudson, B. 2007. Sriksetra survey map 2005-2007. *SOAS Bulletin of Burma Research.* Vol 5, No 1.

King, R.L., Wang, J. 2001. A wavelet based algorithm for pan sharpening Landsat 7 imagery. *International Geoscience and Remote Sensing Symposium, IGARSS '01*, Sydney, Australia, 2001.

McFeeters, S. K. 1996. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *Int. J. Remote Sensing,* 17 (7): 1425 - 1432.

NASA Landsat Program, 2004. Landsat ETM+ scene L71133047_04720011117, Orthorectified, USGS, Sioux Falls.

Ouma, Y. Tateishi, R. 2006. A water index for rapid mapping of shoreline changes of five East African Rift Valley lakes: an empirical analysis using Landsat TM and ETM+ data. *Int. J. Remote Sensing*, 27 (15): 3153 - 3181.

Stargardt, J. 1990, *The Ancient Pyu of Burma. Vol. I, Early Pyu Cities in a Man-Made Landscape*. PACSEA, Cambridge, in association with ISEAS, Singapore, 436 pp., 135 figs., 32 pl.

Stargardt, J. 2001. 'The Historical Geography of Burma; the creation of enduring patterns in the Pyu period.' *Newsletter of the Int. Institute of Asian Studies [IIAS],* Leiden, July, Special Burma Issue.

Stargardt, J. 2003. City of the Wheel, City of the Ancestors: spatial symbolism in a Pyu royal city of Burma, *Indo-asiatische Zeitschrift* [Berlin] 6/7: 144-167.

Xu. H. 2006. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *Int. J. Remote Sensing,* 27 (14): 3025 – 3033.

The Google public geoinformation resources as a new open tool of landscape archaeology

G. Garbuzov
Southern Scientific Centre of the Russian Academy of Sciences, 41, Tchehova Str., Rostov-na-Donu 344006 Russia, garbuz.g@gmail.com

Keywords: landscape archaeology, ancient land division, geographic information, remote sensing, internet

ABSTRACT: New opportunities for studying (recognition, spatial reconstitution, mapping) the remains of ancient cultural landscapes within the bounds of landscape archaeology have been discussed here. The open access to archeologically significant information connected with launch popular internet projects Google Earth/Google Maps was the real information revolution. The potential of the new archaeological research tool can be used in the different applications including comparative inter-regional spatial analysis e.g. ancient land division distribution in the Northern Black Sea region. A testing retrieval of ancient land division features (irregular form) was carried out on the basis of space image data placed on Google portals at the end of year 2007. It is possible to come to a conclusion about existence in Northern Black Sea region only two spacious centres of required land division systems: in a vicinity of antique polis *Olbia* (Lower Dnieper area) and on Asian Bosporus (Taman peninsula). Two separate ancient land division centres among Northern Black Sea coast confirmed by the reliable verifiable facts generates a lot of productive questions. Cartographical internet services can be the most significant principal feature of new toolkit for studying these problems.

In the last some years have opened new opportunities for studying (recognition, spatial reconstitution, mapping) the remains of ancient cultural landscapes within the bounds of landscape archaeology. In fact there was the real information revolution of the open access to archeologically significant information connected with launch popular internet projects Google Earth/Google Maps. These services have been considered as the samples for many another working or scheduled network geoinformation resources. As a result of such remarkable event now we are able to absolutely freely examine of the landscape features through the large part of the Earth from any laboratory (home, field) PC with the spatial resolution in many cases (Quickbird space image layers) comparable to detail air photography. It is especially important in the regions difficult of access in spatial data sense.

The potential of the new archaeological research tool can be used in the different applications including comparative inter-regional spatial analysis. An interesting example of this analysis we can find studying of ancient land division distribution in the Northern Black Sea region. As is generally known from previous local investigations peculiar nonlinear (irregular) form of ancient land division is usually well found on aerial photographs. It seems that quality of the information given nowadays by internet services like Google is quite enough to reveal ancient land division features. A testing retrieval of ancient land division features (irregular form) was carried out on the basis of space image data placed on Google portals at the end of year 2007.

It is possible to come to a conclusion about existence in Northern Black Sea region only two spacious centres of required land division systems in a vicinity of antique polis *Olbia* (Lower Dnieper area) and on Asian Bosporus (Taman peninsula) (fig. 1). Features of such systems were revealed here before by analysis of archival aerial photographs (Liseckij, 1994; 2000; Gorlov & Lopanov, 1995; Paromov, 2000; Garbuzov 2006; 2007). Outside the named areas ancient land division features somewhere in Northern Black Sea region in a little comparable scales it is not marked. Only small fragments of such land division are allocated by “internet” space images in some other points: in the neighbourhood of antique *Nikonion* – Lower Dniester area (Brujako *et al.*, 1991, p.38, fig. 1) and near antique *Kerkinitis* -Western Crimea (Kolesnikov & Jacenko, 1999, p. 307-311, fig. 2, 16, 17). In addition the remains of ancient roads different from linear scheme were noticed on aerial photographs from north-western part of Crimean Peninsula (Ščeglov, 1978, p. 53).

In the East Crimea (European Bosporus) ancient land division features in a “normal” irregular form are not revealed yet so it represents one of paradoxes of the comparative inter-regional spatial analysis. Some separate parts of local land division net was measured and described with details in works concerned rural economy of Bosporus Kingdom (Kruglikova 1975, p. 54-57, 127-131, fig. 18, 19, 68). Specific non-linear ancient land division from the East Crimea was also studied for a long times at the Azov Sea coast (Maslennikov & Bezručenko, 1991; Maslennikov & Smekalova, 2005). Differences in land division systems between European and Asiatic part of the Bosporus Kingdom can be resulted from different fertility of the ground causing also differences in economical systems.

The statement of two separate ancient land division centres among Northern Black Sea coast confirmed by the reliable verifiable facts generates a lot of productive questions. One of them for example why we have discovered in so distant regions with different ways of historical evolution high degree of photometric and topological analogy. The other question concerns characteristic of the land division system existed close to *Olbia.* Here except remains of typical non-linear land division system forming quasi squares or rectangles of different dimensions also slight light traces of more detailed divisions are readable both on air photographs and "internet" space images (fig. 2). The last ones can confirm the existence of field arranged as ridge-and-furrow in the way similar to that known in Medieval Europe. Remains of similar land division system have been discovered close to antique *Kytaia* at Kerch Peninsula (Čendev & Kulikov, 2004).

It will be interesting to compare these two spacious centres taking into account all factors important for organisation of space. While at Taman Peninsula existed natural borders were used also as the borders for land division system at the region close to *Olbia* it is very difficult to find close-straight connections between natural and artificial divisions.

To return to the more generic subject it should be emphasized that all land division finding based on considerable publicly available set of involved data. The opportunity to rely on the open verifiable remote sensing facts given cartographical internet services is very likely the most significant principal feature of new toolkit.

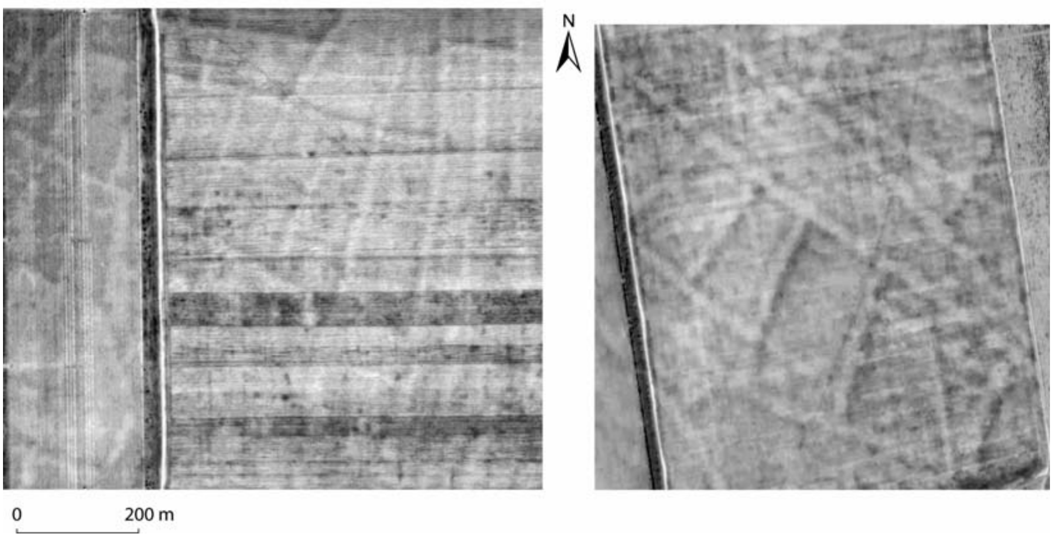


Figure 1. Left – ancient land division of Taman peninsula, QuickBird/DigitalGlobe image (7 Sept. 2007) from Google portal, right - ancient land division near Olbia, QuickBird/DigitalGlobe image (13 June 2003) from Google portal

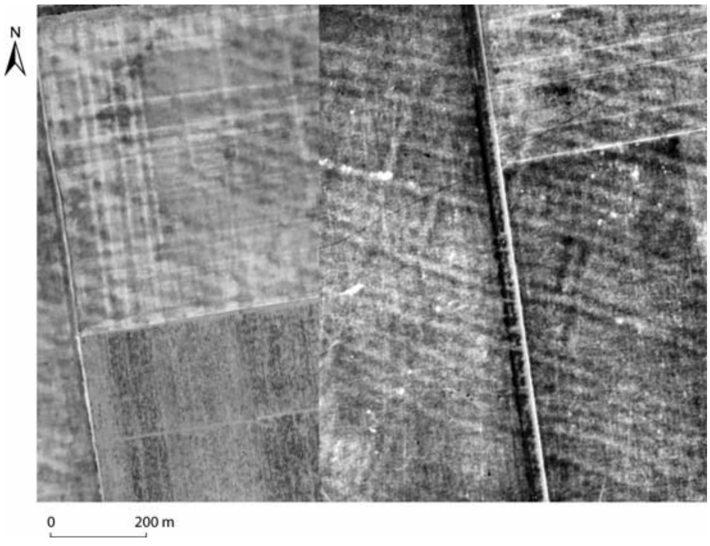


Figure 2. Ancient land division near Olbia: left - QuickBird/DigitalGlobe image (13 June 2003) from Google portal, right – aerial photograph, after (Paromov, 2006, slide 8)

REFERENCES

Brujako, I.V., Nazarova, N.P., Petrenko, V.G. 1991. Drevnie kul'turnye landšafty na uge Tiligulo-Dnestrovskogo meždureč'ja po dannym aerofotosjemki. *Severo-Zapadnoe Pričernomor'je – kontaktnaja zona drevnich kul'tur*. Kiev: 37-44.

Čendev, J.G., Kulikov, A.V. 2004. Antropogennye modifikacii počv v okrestnostjach antičnogo Kiteja. *Rossijskaja archeologija* 3: 44-54.

Garbuzov, G.P. 2006. Drevnee zemleustrojstvo nelinejnogo tipa i charakteristiki sovremennogo landšafta Tamanskogo poluostrova. *Drevnosti Bospora* 9: 36-66.

Garbuzov, G.P. 2007. Kratkij obzor drevnego zemleustrojstva Tamanskogo poluostrova. *Drevnosti Bospora* 11: 59-85.

Gorlov, J.V., Lopanov, J.A. 1995. Drevnejšaja sistema melioracii na Tamanskom poluostrove. *Vestnik drevnej istorii* 3: 121-137.

Kolesnikov, A.B., Jacenko, I.V. 1999. Le territoire agricole de Chersonèsos Taurique dans la région de Kerkinitis. In Brunet, M. (Ed.) *Territoires des Cités Grecques. BCH. Suppl.* 34: 289-321.

Kruglikova, I.T. 1975. *Sel'skoe chozjajstvo Bospora*. Moskva.

Liseckij, F.N. 1994. Sistema antičnogo zemleustrojstva v Nižnem Pobužje. *Drevnee Pričernomor'je. Kratkie soobščenija Odesskogo arheologičeskogo obščestva*. Odessa: 237-242.

Liseckij, F.N. 2000. *Prostranstvenno-vremennaja organizacija agrolandšaftov*. Belgorod.

Maslennikov, A.A., Bezručenko, I.M. 1991. Zemel'nye nadely antičnogo vremeni v Krymskom Priazov'e. *Kratkie soobščenija Instituta Arheologii* 204: 37-45.

Maslennikov, A.A., Smekalova, T.N. 2005. Sledy drevnego zemlevladenija i zemlepol'zovanija na chore Evropeiskogo Bospora (Vvedenie v temu). *Drevnosti Bospora* 8: 276-307.

Paromov, J.M. 2000. O zemel'nych nadelach antičnogo vremeni na Tamanskom poluostrove. *Archeologičeskie vesti* 7: 309-319.

Paromov, J.M. 2006. Osnovy primenenija aerofotosjemki v archeologii. In Korobov, D.S. (Ed.) *Archeologia i geoinformatika* 3. Moskva, Institut archeologii RAN. (CD-ROM).

Ščeglov, A.N. 1978. *Severo-Zapadnyj Krym v antičnuju epochu*. Leningrad.

Archaeological exploration in the Talakadu region along the bank of the Cauveri river, Karnataka, Southern India using multi-sensor satellite data and Geographic Information System (GIS)

M.B. Rajani[1], A.S. Rajawat[2], M.S. Krishna Murthy[3], J. Kamini[4], Srinivas Rao[4]

1 National Institute of Advanced Studies (NIAS), Indian Institute of Science Campus, Bangalore 560 012, India, rajanihf@gmail.com

2 Space Applications Centre (SAC), Ambawadi Vistar P.O., Jodhpur Tekra, Ahmedabad 380 015, India, asrajawat@sac.isro.gov.in

3 Archaeology and Ancient History, University of Mysore (Retd.) Rashmi, 5th Main road, Vani Vilas Puram, Mysore 570 002, India

4 National Remote Sensing Agency (NRSA), Balanagar, Hyderabad 500 037, India

Keywords: Remote sensing, multi sensor studies, ground truth, GPS, GIS, Talakadu site.

ABSTRACT: Talakadu is an archaeological site in southern India situated on the bank of river Kaveri. The peculiar configuration of the river flow has accumulated large amount of river sand on the curved bank and the annual monsoon wind has carried the fine sand to the north east direction over the last few centuries burying the site. There are five well-known temples, which were constructed between 10th and 14th century AD. The Directorate of Archaeology and Museums of Karnataka together with University of Mysore conducted excavations at 7 locations (numbered TK 1 to 7) in Talakadu from 1992-93. Most of the trenches yielded fruitful results: in consequence the nature, history and archaeology of the site came to be better understood, though only about less than 1% of the total sand covered area has been excavated. The sand accumulation vertically ranges between 2 to 30 feet or more covering an area of 4.5 km sq. In early 19th century trees were planted in this area to arrest the movement of wind-blown sand.

Present study has analyzed multi spatial, spectral and temporal satellite data using digital interpretation techniques to identify features of archaeological significance. The study has attempted to correlate known archaeological sites excavated so far and identify new areas for exploration by data integration in GIS. GPS survey of the area was conducted to establish a spatial relation between known locations (existing temples and excavated areas) and the potential locations (seen as anomalies on the satellite data) that may contain buried archaeological remains. This has lead to identifying four anomalous features for further exploration.

1 INTRODUCTION

Talakadu is a historical place on the bank of river Kaveri in southern India. It served as the capital of Ganga dynasty from 8th century and was subsequently inhabited by four other kingdoms in the following ten centuries. Influences of different dominions are reflected in the cultural remains such as architecture and artifacts found in the site. There are five well-known temples, which were constructed between 10th and 14th centuries AD. Talakadu is famous for extensive accumulation of sand in the form of dunes.

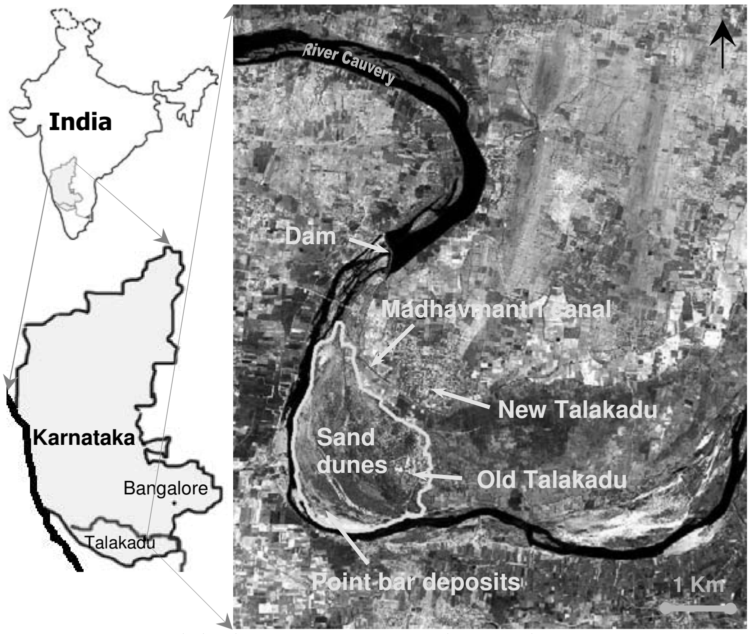


Figure1. Talakadu area (Karnataka, India) as seen on Resourcesat-1 LISS-IV FCC Imagery of March 23, 2007

The current unique disposition of the site is the result of the area's geomorphology, anthropogenic activity and wind patterns. Archaeological excavations in the old Talakadu area have revealed fluvial silt and sand which show that the original course of Kaveri was close to the town and probably the town itself is on the flood plain. Repeated flooding has brought gravel and sand which get deposited on the concave side of the meander resulting in lateral south westward migration of the river. There are other meanders and point bar deposits in the course of Kaveri but it is only at Talakadu that sand dunes have developed (Srikantia, 1997).

The dam, clearly visible in the image (figure *1*), on the north of Talakadu, was originally built in 14th century AD by Madhava Mantri, and must have supplied water to the old Talakadu area. At present the dam supplies water to the paddy fields on the east side of Talakadu. The construction of the barrier across Kaveri north of Talakadu and diversion of river water by Madhava Mantri canal created lower water stages in the river downstream and exposed vast stretches of the point bar deposits southwest of old Talakadu creating the main source of sand for the dunes. The southwest to northeast blowing monsoon winds are the main carriers of sand in Talakadu area. The sand covered area constitutes about 4.5 sq km and is marked with a yellow boundary in figure*1*. There are five popularly known temples in this area: Vaidyeshvara (V), Kirtinarayana (K), Maralesvara (M), Pataleshvara (P) and Chaudesvari (C) temples (see figure *2*). V (14th cen. AD) is a large fine granite structure, said to have been built by Madhavmantri, the local Minister of Vijaynagara period; K is a granite structure, maintained by Archaeological Survey of India. It was built in 1117 AD by King Vishnuvardhana, of Hoysala dynasty. Parts of the temple were buried under the dunes till after mid 20th century. Later the area was cleared of sand exposing the sides of the temple; P and M are similar and were built by Rachamalla IV of Ganga dynasty in *c*. 1000 AD. The exterior has undergone renovation, hence losing of its style and shape. The top of the towers of these temples are few feet below the surrounding sand level; C is adjacent to the sand dune area and built in 11 century AD.

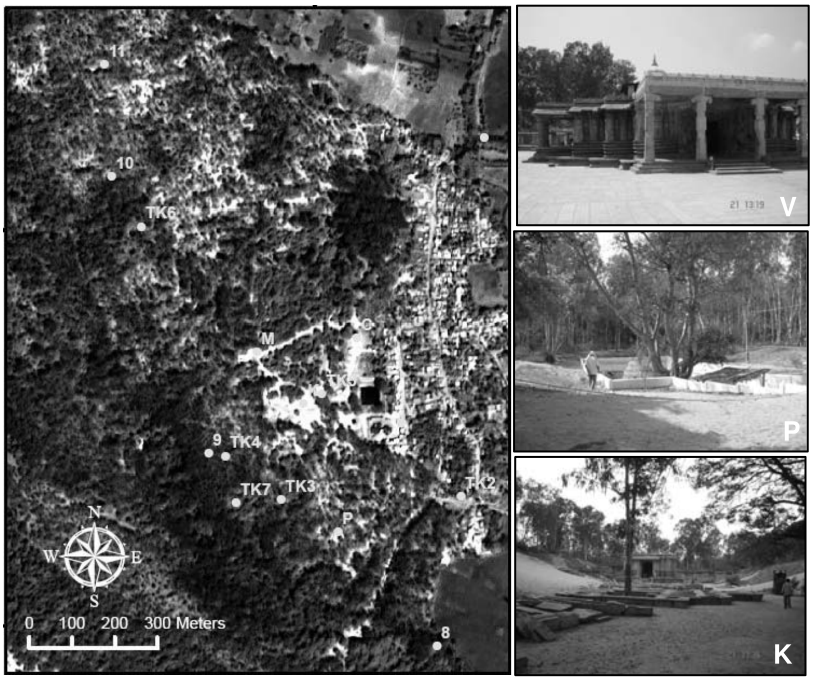


Figure 2. Spatial distribution of known archaeological sites in Talakadu superimposed on Cartosat-1 PAN and Resourcesat-1 LISS IV merged FCC

The Directorate of Archaeology and Museums of Karnataka together with University of Mysore conducted excavations in Talakadu between 1990s in 7 locations (numbered TK 1 to 7, figure *2*) and published an extensive report. The choice of location depended on three criteria: firstly archaeologically potential (identified by tell tale signs or objects such as brickbats, potsherds scattered on the surface), secondly less sand deposit and thirdly less vegetative cover. The highlights of the excavations were Megalithic objects in TK4, terracotta ring wells and metal objects in TK5, brick foundation of a Jain temple in TK6 and TK7 revealed brick built wind breaker wall and water supply system having underground brick masonry channels, a collection tank and a small bathing pond.

Apart from these well documented sites and monuments, there are remains of a ruined temple partly buried under sand cover. The base of the temple probably is 4-5 ft under present sand level. There are trees growing on top of the stone structure of the temple with roots penetrating into the crevices (see *figure 4* in (8)). Parts of a wall structure is visible in the exposed trenches in two sites (figure 4 in (9 and 11)). Partially exposed ruins with scattered structural and sculptural remains of a Siva temple were noticed on the surface (figure *4* in (10)).

The present study involves digital analysis of multisensor satellite data along with GIS techniques to understand and interpret anomalous tonal and textural patterns of the known archaeological sites in the study area and identify intervening or extension zones for further exploration. Linear features and geometric patterns either of positive or negative vegetation marks were detected (see *figure 3*). These can be interpreted meaningfully only if they are understood in the context of known information about the site. The information obtained from conventional method of archaeology should be integrated with remote sensing. This is able to detect features with a synoptic perspective of the whole site whereas conventional methods unearth information in point location with grids of 1 or more of 5x5 m. Results of the excavations together with drawing of structure and material found in them have been published (Devaraj et al., 1996). But there is no accurate map showing the exact geographical location of these excavation sites. Therefore for integrating information from the two domains of remote sensing and archaeology it is essential to identify the exact locations of excavation sites on remote sensing data.

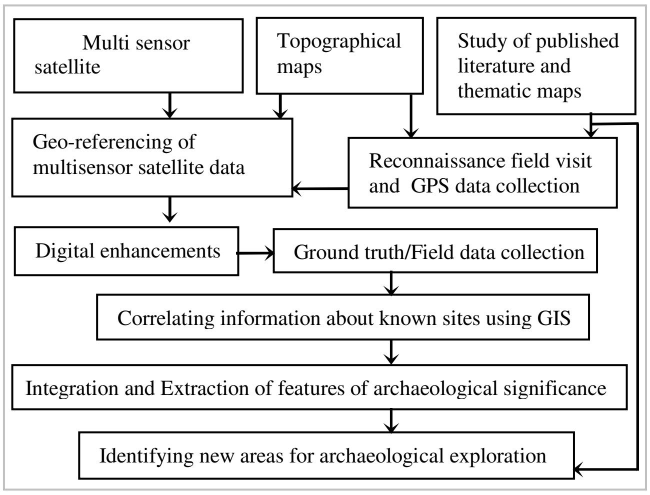

Multi sensor satellite
Topographical maps
Study of published literature and thematic maps
Geo-referencing of multisensor satellite data
Reconnaissance field visit and GPS data collection
Digital enhancements
Ground truth/Field data collection
Correlating information about known sites using GIS
Integration and Extraction of features of archaeological significance
Identifying new areas for archaeological exploration

Figure 3. Work flow of the study

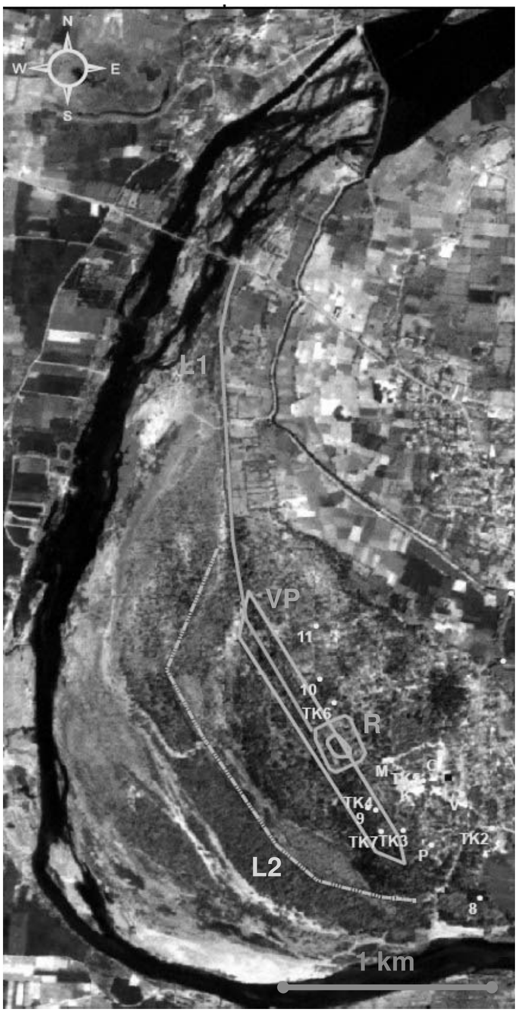


Figure 4. Features extracted from RS data for further archaeological exploration.

2 MATERIALS AND METHOD

Figure *3* summarizes the materials and method used for the study. In addition, topographical maps at the scale of 1:250,000 and 1:50,000 scale were utilized for understanding the terrain and geocoding the satellite imagery. GPS was utilized for ascertaining coordinates of excavated sites and further improving the geocoding of the data. Geomatica, ERDAS Imagine and ENVI image processing s/w were used for geocoding, enhancing and merging multisensor satellite data. For further details about data and image processing methods used for this study see Rajani and Patra, 2008.

The data of different sensors and dates were registered and analyzed individually. Among the five temples three (V, K and M) can be readily identifiable on all imagery. None of the seven excavation sites can be identified because of their size, sand and vegetative cover. For this purpose it was decided to conduct a GPS and ground truth survey of this area to establish the exact location of the excavations and to conduct ground observations of features marked in figure *2*. The locations of temple and previously excavated archaeological sites (identified through GPS) were marked on the imagery. An attempt was made to correlate the known archaeological locations with the spectral and spatial patterns in multi sensor and temporal satellite data products. Correlated patterns/shapes indicating intervening and extension zones such as alignments of known sites along linear pattern, anomalous rectangle patterns and vegetation patches were traced and extracted as separate layers using GIS tools. All the features indicating modern activities such as roads, modern buildings were excluded. These layers were then verified on the ground.

3 RESULTS AND DISCUSSIONS

A linear pattern of vegetation (L1) of 2.4 km long and 5-10 m wide is noticeable in all datasets (figure *4*). This indicates a positive crop mark (Wilson 2000), one of the important indicators of buried archaeological objects. The high moisture content in the subsurface due to presence of buried ditches or canals manifests as strong vegetation patterns on the surface (Rajani 2007). L1 connects the Madhavmantri dam and the area of old Talakadu. Considering that the dam was originally built in 14th century, L1 is inferred as the canal through which water may have been supplied from the reservoir to the Old Talakadu area. Another linear feature L2 is discernable surrounding the western boundary of old Talakadu. This appears to be intermittently connected positive vegetation marks. Considering that on the northern end L2 appears to be branching out of L1, contingent upon L1 being old canal L2 could be a distributory. But L2 shape and its location having all the known sites to its one side could suggest that it is more likely to be a wall/fortification or bund protecting the settlement area. At the southern end of L1 a rectangular feature appearing as negative vegetation mark and measuring around 170 x 200 m in dimension is observed. The centre of this rectangular feature appears as positive vegetation mark. This pattern suggests the subsurface might contain some kind of reinforced rectangular outer structure. This feature is distinctly observed in mainly coarser resolution LISS-III data sets. A linear patch of vegetation (VP) in NW-SE direction is observed with 1.2 km length and 100 m width across old Talakadu region. This patch includes parts of L1 and R discussed above and extends beyond them towards south. This patch is probably due to high moisture content in the area. Conditional upon our interpretation of L1 being correct, VP could suggest the old canal (L1) extends further south. Two archaeological features support our interpretation of VP. Firstly, past excavation in TK7 has revealed a bath that was part of royal enclosure, giving evidence of water being drawn to TK7 which is located within the patch of high moisture content VP. Secondly, an inscription dating 1514 A.D. (Devaraj *et al.*, 1996) found nearby mentions the grant of cultivated wet land on the west of Kirtinarayana Temple (K), which also comes within or close to VP. The above-mentioned four features (L1, L2, R and VP) are recommended for further exploration.

An important issue always to remember while dealing with many layers of GIS information is to project all the layers in a common projection and datum/ellipsoid. Though some softwares prompt if one is trying to view two layers with different projection, some other softwares are not sensitive to differences in projection. In such cases features in two layers can be displaced sometimes by hundreds of metres which will make interpretation based on comparison almost meaningless!

4. CONCLUSION

The present study has demonstrated an approach for archaeological exploration by utilizing high resolution multi spectral satellite data and insitu archaeological data integrated in GIS. This study has used GPS on ground to obtain the coordinates of excavations conducted by Department of Archaeology and Museums, Karnataka and plot them on remote sensing data and analyze the anomalous patterns in context of already known archaeological information. The anomalies that have been noticed on remote sensing data are larger features but are part of the very same settlement. This integrated study has identified four new features for further archaeological exploration/excavation.

REFERENCES:

Devaraj, D.V., Narasinha Murthy, A.V., Krishna Murthy, M.S., Swamy 1996. *Excavations at Talakaḍ*, Directorate of Archaeology and Museums, Mysore.

Rajani, M.B. 2007. Bangalore from above an archaeological over view, *Current Science*, 93(10): 1352-1353.

Rajani, M.B., Patra, S.K. 2008. 'The applicability of image processing techniques for archaeological exploration using space imagery: Talakadu - a case study' in Lasaponara, R., Masini, N. (Eds,) Proceedings of Workshop on "Advances in Remote Sensing for Archaeology and Cultural Heritage Management".

Srikantia, S.V., Anantharamu, T.R. 1997. The Talkad sand dunes in Mysore district of Karnataka – their description, evolution and origin, *Geological Society of India*, 50: 315-321.

Wilson, D.R. 2000. *Air photo interpretation for archaeologists*, Tempus, Gloucestershire, UK.

ACKNOWLEDGEMENTS

We thank Dr. K. Kasturirangan, Director, NIAS, and Dr. R.R. Navalgund, Director, SAC, for their overall guidance, Institutional support and encouragement in carrying out this study. We also thank Prof. B.V. Sreekantan at NIAS and Dr. V. Raghavswamy at NRSA for useful discussions. We thank Dr. R. Gopal, Director and Dr. Gangadhar, Deputy Director, Directorate of Archaeology and Museums, Govt. of Karnataka, for guidance and support during field visits.

9

International Archaeological missions as outstanding ‘laboratories’ of archaeological science

Planning the Archaeological Park of Chan Chan (Perù) by mean of satellite images, GIS and photogrammetry

F. Colosi[1], G. Fangi[2], R. Gabrielli[1], R. Orazi[1], A. Angelini[1], C.A. Bozzi[2]

1 CNR-ITABC, via Salaria km. 29,300 – 00016 Monterotondo St. Roma, Italia
francesca.colosi@itabc.cnr.it; roberto.gabrielli@itabc.cnr.it; roberto.orazi@gmail.com
2 Università Politecnica delle Marche – via Brecce Bianche 60131 Ancona, Italia
g.fangi@univpm.it

Keywords: Chan Chan, Archaeological Park, Documentation Centre, Restoration

ABSTRACT.
Chan Chan (IX e XV sec. A.D.- UNESCO World Heritage List since 1986) is the America's greatest pre-Columbian town built in adobe (14 km²) and represents the material and immaterial synthesis of ten thousands years of autonomous evolution of the pre-Columbian cultures in northern Peru.
From 2001 the MIPE (Missione Italiana in Perù) is operating at Chan Chan carrying on a wide action of documentation, conservation and exploitation. The most important purpose of the work is represented by the restoration of Palacio Rivero, the smallest of the Chan Chan palaces, and by the protection of the site from the aggressive and uncontrolled growth of the near town of Trujillo by the creation of an Archaeological Park.
The strategic objective of the work is to integrate all the actions related to the archaeological research, conservation and exploitation of the site with all the actions addressed to the promotion and the social development of its population.
The extensive settlement of Chan Chan cannot be analysed and studied without using great scale images as the high resolution ones from the Quickbird satellite used for the quantitative measurement of the deterioration and the detailed analysis of the landscape.
These images represent the cartographic base of the GIS called "The Archaeological Park of Chan Chan" planned as a mean of management and valorisation of the archaeological complex and of its territory.
The final objective of such a system, that is going to be managed in a specific Documentation Centre, is the gradual creation of a multidisciplinary data archive that will allow the various research and conservation actions to be updated and to schedule and implement the improvement procedures, as well as to regulate the various economic activities related to the management of the complex (tourist flow, multimedia products, constraints and integration with the modern city).
Finally the restoration of *Palacio Rivero,* as an example of Chan Chan architecture, represents an operating model allowing the execution and relative application of IT to all the phases of documentation, research, and restoration. The geometrical survey of the palace was performed using different techniques as Total Station, GPS, laser scanner and aerial and ground photogrammetry.

1 THE ARCHAEOLOGICAL COMPLEX

The town of Chan Chan (IX cent. A.D.) has been the political, religious and administrative capital of the Chimù civilization and represents its most important material expression (Moseley & Kent, 1982).

The city occupies a very large area of the Moche valley, at about 600 km north of Lima, and it is placed on a natural terrace that decreases towards the ocean (from 40 to 20 m above the sea level). The complex is formed by nine great palaces or *ciudadelas,* five *huachas* or stepped pyramids and wide areas of minor residential architecture (Figure 2).

Some very long and pedestrian paths allowed the functional distribution of the urban settlement and connected the town with the cultivated fields and with the *humedales,* or open areas located between the town and the ocean, where the Chimù grew the *totora*, a kind of reed used to construct small fishing boats called *caballitos de totora (*Campana Delgado, 2006).

Chan Chan is the greatest settlement of Latin America built in *adobe*, a building technique which is still used alone the Peruvian coast for minor architecture (Kolata, 1990). This peculiarity, together with the imposing dimensions of the town and with the possibility, still available, of reading the different elements that formed the original historical landscape, have allowed UNESCO to inscribe the site in the World Heritage List.

The plan to manage the complex, which was requested by UNESCO and which was prepared by the Instituto Nacional de Cultura (INC), has been approved by the Peruvian Government in the year 2000. The *Plan Maestro de Conservación y Manejo del Complejo Arqueologico Chan Chan* (Plan Maestro) provides for a number of projects addressed to the archaeological investigation, the documentation and the conservation of the mud bricks structures and the related decorated surfaces.

The Complex of Chan Chan represents an extremely important cultural resource for the development of actions of “integrated conservation” and, therefore, for the improvement of the socio- economic conditions of the population.

2 STUDY OF THE TERRITORY BY MEAN OF SATELLITE IMAGES

In order to analyze the enormous archaeological complex and its territory we have been using an image of the Quickbird satellite (kindly offered by Euroimage) which, in the panchromatic band, has a resolution of 60 cm. The characteristics of the image, which allow to work a different scale of definition, have permitted us to analyze the different elements of the territory and to register the critical relationship among the archaeological complex, the town of Trujillo and the uncontrolled formation of *pueblos jovenes*, or unauthorized settlements lacking in any type of infrastructure or public service.

The different elements of the territory (as water, vegetation, arid grounds, cultivated area) have been pointed out by mean of image classification techniques (Fangi *et al.*, 2005).

With the aim to improve the quality of the information regarding architectural and archaeological structures a fusion between the real colour and the panchromatic images has been performed together with a second fusion between the infrared and the panchromatic ones in order to study soil and vegetation. The new images keep all the information of the real colour and the infrared shots but achieve the high resolution of the panchromatic one. Beside the visible archaeological structures they show also architectural alignments which are not visible on the ground, providing therefore an important tool for the identification of buried structures (figure 1).

The comparison between photographic images of different periods (IGN 1961, SAN 1980) and the satellite image (May 2003) has allowed the reconstruction of the urban development of the town of Trujillo during the last fifty years, the evaluation of its imposing rating of development and the planning of preservation measures. At the some time the comparison of the Quickbird image with the photos of the photogrammetric aerial survey produced by University of Harvard in 1970, has pointed out the high level of degradation suffered by the *adobe* structures in the last 35 years (Colosi *et al.*, 2006; Colosi *et al.*, 2007).

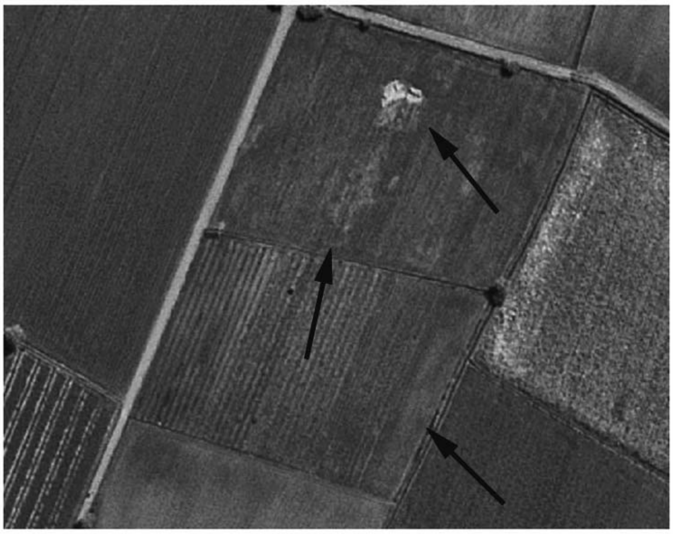


Figure 1. Example of data fusion. The black arrows show some burial structures

3 GIS AND MANAGING OF THE COMPLEX

One of the main objectives of the Italian Mission in Perù (MIPE) is to protect the archaeological site from the urban growth of the town of Trujillo by mean of planning an Archaeological Park based on different functional areas controlled by different kinds of obligations (Colosi & Orazi, 2003).

For this purpose we have defined by differential GPS the polygonal that marks the archaeological area (in red in figure 2), within which the most important monuments of Chan Chan are located. At the same time we have prepared a proposal to define the perimeter of an external protection area which stretches all around the archaeological one up to the present limits of the town of Trujillo (in green in figure 2) .

For what is regarding the definition of the monumental area, the polygonal approved by law during the fifties was correctly positioned on the territory while the extension of the protection area, subject to legal and building restrictions, was agreed together with the INC, the Municipality of Trujillo and the PlandeMetru (Office for the Master Plan of the town of Trujillo).

The safeguard and valorisation of a such extended territory can be solved only by mean of IT and, in particular, through the realization of a GIS that could manage the relations between cartographic, archaeological, environmental and planning data.

The Quickbird satellite image, correctly georeferenced, represents the cartographic base of the GIS named "Archaeological Park of Chan Chan", where all the information which was possible to find on the archaeological site were registered (technical and historical cartography, aerial photos, GPS survey of the archaeological structures, restoration actions). The thematic map of figure 3 is an output of the GIS, in which the boundaries of the archaeological and of the protection area, some *huachas* (Las Conchas, Caballo Muerto, Algodon, Mirador – in red), the Chimu pedestrian paths (in orange), the *huachacas* and the related raised paths (in yellow) have been positioned on the satellite image. All this elements, which are clearly visible on the territory, provide an almost untouched image of the ancient landscape.

The will to allow the most wide diffusion of information implies that the system be consultable in the web while the whish to develop the tourist flow involves a proper system architecture that be interactive and open to possible integration by no specialist users. The collaboration started in 2007 with the LabGis of the Geological Science Department of the University of RomaTre, has allowed us to create a specific web site.

4 TRIDIMENSIONAL MODEL AND FRUITION OF THE COMPLEX

The essential elements to allow a proper fruition of a complex of such dimensions are defined by the realization of an adequate barrier surrounding the archaeological area and by the drawing up of a visiting strategy. The first will be useful to avoid invasions by peasants, house builders or criminals that, at the moment, make dangerous the visit of the architectural structures.

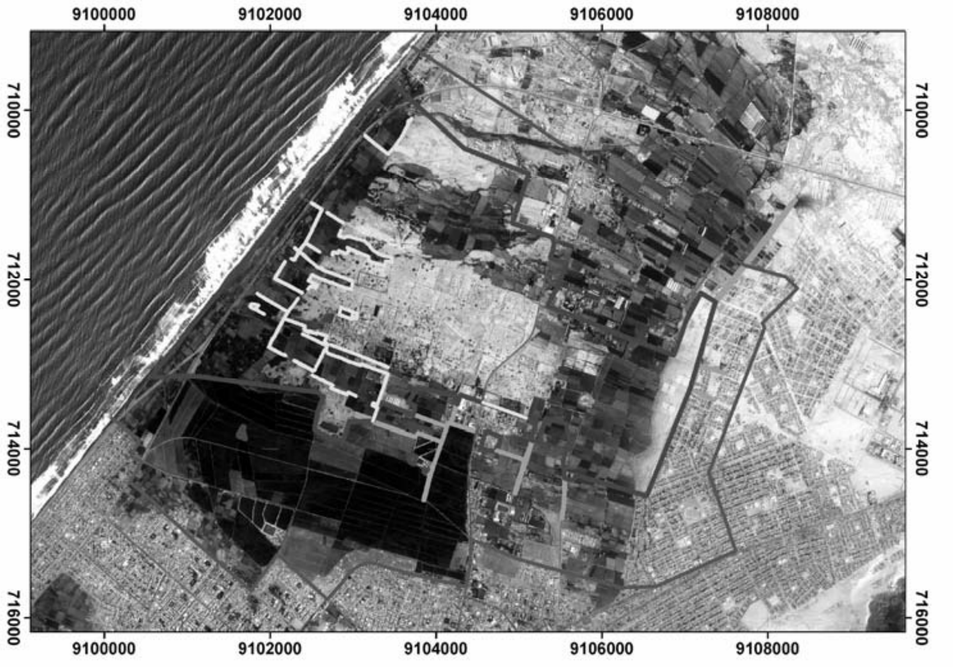


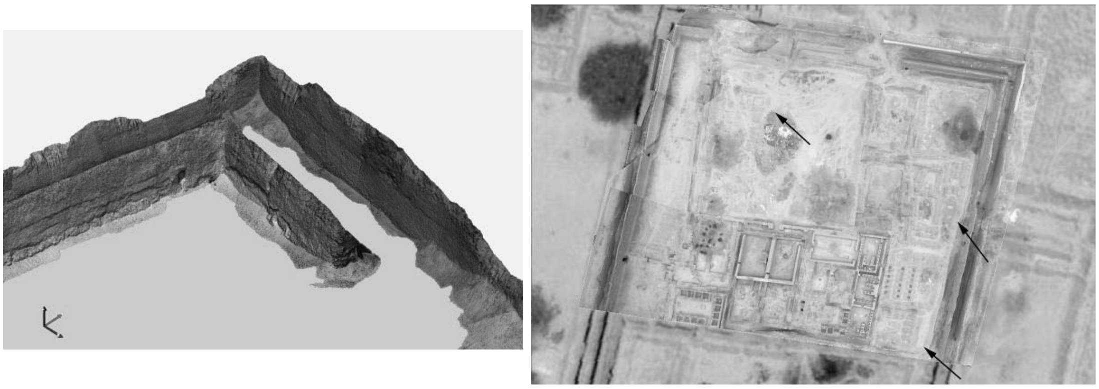
Figure 2. Archaeological Park of Chan Chan. A thematic map of the GIS

The visiting strategy is based on the possibility on visiting Palacio Tschudi, which is the unique partially restored *ciudadela*, and on the creation of a virtual and multimedia pre-visit in order to allow the tourist to make knowledge of the complex, of its history and of its different monuments .

The Documentation Centre, forwarded in the Plan Maestro, will lodge the archive of digital data, an equipped positioning for the virtual visit and an hall for conferences related to the progress of the archaeological investigation.

As regards the Documentation Centre, we have started a tri-dimensional survey of Palacio Rivero, the nearest to Palacio Tschudi, in order to create the 3D model for the virtual visit and to present the different architectural elements.

Due to the peculiarity of the architectural structures (outside main walls which are 10 m. high and are separated by a corridor 3,50 m. wide; lack of definite architectural points due to the degradation of the walls), we are performing the geometrical survey using a photogrammetric system based on a serial of three pictures (Menci Software – Zscan) with shots both from ground level (outside main walls) and from aerostatic balloon (figure 3). The low altitude pictures have allow us to create a first photomap of the northern sector of the palace in which some architectural alignments, which may not be seen on the ground, are clearly visible (figure 4).



Figures. 3/4. Photogrammetric reconstruction of the outside main walls (N/E corner). Photo mosaic of the northern part of Palacio Rivero overlapped to the Google Earth image. The black arrows show some architectural alignments which are not visible on the ground

5 REFERENCES

Campana Delgado C. 2006.*Chan Chan del Chimo. Estudio de la ciudad de adobe más grande de América antigua*, Orus, Lima (Perù)

Colosi, F., Orazi, R. 2003. Integrated Technologies for the Study, Documentation and Exploitation of the Archaeological Area of Chan Chan, Peru. In *Proceedings of the International Conference on the Study and the Conservation of Earthern Architecture* - Terra 2003, Yazd, Iran, 29 Nov - 2 Dic. 2003.

Colosi, F., Fangi, G., Gabrielli, R., Orazi, R., Peloso, D. 2006. Operative action for the conservation of the Archaeological Complex of Chan Chan, Perù, in *From Space to Place. Proceedings of the Second International Conference of Remote Sensing in Archaeology* , Roma, 4 – 7 dic. 2007, 439 - 445

Colosi, F, Lentini, A., Orazi, R. 2007. Il Parco Archeologico di Chan Chan: GIS di gestione e prime indagini archeometriche, in *Atti del XXIX Convegno Internazionale di Americanistica*, Perugia 2-7 maggio 2007

Fangi, G., Malinverni, E. S., Schiavoni, A. 2005. Integrated surveying techniques for the Archaeological Park of Chan Chan in Perù, in *Atti del XX International Simposium CIPA*, Torino, 26 settembre – 1 ottobre 2005, 259- 265

Kolata, A. 1990. The Urban Concept Of Chan Chan, , in Moseley M., Cordy Collins A. (Eds), *The Northern Dynasties: Kingship and Statecraft in Chimor*, Washington, Dumbartón Oaks Research Library and Collection, 107 – 145

Moseley, M. E., Kent, D. (Eds) 1982. *Chan Chan, Andean Desert City*, Albuquerque, University of New Mexico Press.

Image analysis and measurement applied to the archaeological materials from Pyrgos (Cyprus).

M. R. Belgiorno, A. Lentini

CNR Istituto per le Tecnologie Applicate ai Beni Culturali - Area della Ricerca di Roma 1, Via Salaria Km 29,500 C P 10, I- 00016 Monterotondo St.(Roma), e-mail: alessandro.lentini@itabc.cnr.it

Keywords: measurement, archaeobotany, paleopalinology, pottery, glass

ABSTRACT.

The architectural complex of Pyrgos has an extension of more than 4000 sq. m., calculated by resistivity testing, Until 2005, the excavation brought to light only the 30 % of the architecture remains, corresponding to the sector devoted to industrial activities. The area investigated has in the middle a large olive pressroom furnished with ten storage jars (containing 500-300 litres of oil each) and a laboratory for extracting olive oil scents. On the western wing, there is a room for dyeing and weaving textiles (connected with a second room mainly for cosmetics and medicaments). In the North and the South there are two large courtyards and two small workshop full of implements and facilities to produce metal objects. The total excavated area of Pyrgos complex is approximately 1200 sq. meters.The morpho-biometric study of the different archaeobotanical material (seeds, drupes, berries, pollens and textile fibres) and morphology residues of different colours, molluscs and various sections/types of pottery and fragments of glass opaque and semitransparent (red, blue, violet, yellow, green, orange, white and colourless), was carried out with an image analyser. The image analysis system was composed of various technical components a JVC C322 RGB microscope video camera mounted on a optical microscope, and a optical stereo microscope connected to a computer with a video imaging board and a high resolution monitor in order to characterise the obtained images. A new software programme Image Analysis and Measurement permitted either black and white or colour pictures to be acquired. The images obtained through the optical video microscope were acquired in true colour, in order to avoid the false colours obtained with commercial software. Pictures were acquired as Raster (binary matrix with an x - y origin) images, which may reach a maximum size of 1200 pixels.

1. INTRODUCTION

The site of Pyrgos-Mavroraki near Limassol in Cyprus, destroyed by an earthquake in 1900-1850 B.C (Belgiorno M.R., 2004)., is situated in an elevated position in the center of a vast settlement of the Ancient and Middle Bronze Age before the Calcolitic period. The unchanged position of the structures and the finds, that remained unknown for 4000 years near the homonym village, offers a unique opportunity to carry out archaeometric investigations on totally uncontaminated materials. The areas, investigated in eight years of excavations, concern two vast courtyards and two workshops for the production of bronze objects, an oil-mill with store for the jars, a workshop for the production of perfumes-medicinal substances, the latter located in the north-eastern corner of the large oil-mill, besides there are two environments used for textile production and a room for winemaking.

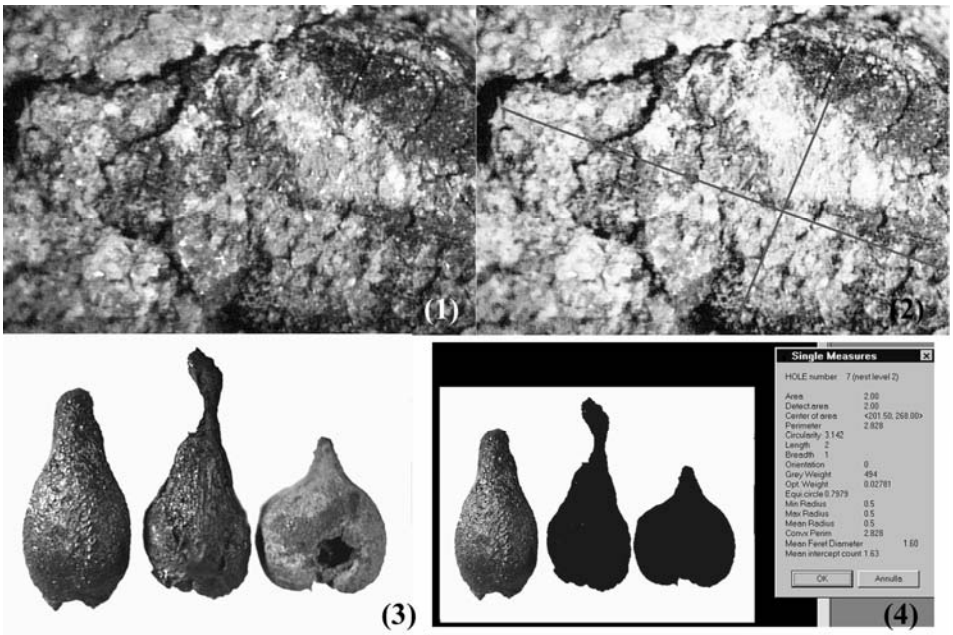
2. MATERIALS AND METHODS

The morpho-biometric study of the different archaeobotanical materials (seeds, pollens and textile fibres) and various cross-section of pottery and fragments of glass opaque and semitransparent (red, blue, violet, yellow, green, orange, white and colourless), was carried out with an image analyser. The image analysis system was composed of various technical components a JVC C322 RGB microscope video camera mounted on a James Swift MP 3502M microscope, and a Nissho optical stereo microscope connected to a computer with a video imaging board and a high resolution monitor in order to characterise the obtained images. A new software programme "Image Analysis and Measurement" (Findlay, 1995) permitted either black and white or colour pictures (Hanbury & Serra, 2001) to be acquired. The images obtained through the optical video microscope were acquired in true colour, in order to avoid the false colours obtained with commercial software. Pictures were acquired as Raster (binary matrix with an x - y origin) images, which may reach a maximum size of 800 x 600 pixels. A colour threshold (Grieson, 1986) common to all morphologies was established through operations in which particular areas / zones of the image (Berns, 1999) under study were evidenced. Diameters, numbers, area, radii, and orientation of several morphologic characteristics were extracted automatically. In addition a series of mathematical equalisations, scaled enlargements and geometrical reflections made it possible to evidence particular distinctive structural features both in the archaeobotanical remains. The system also allows the video images to be saved in B / W or RGB as TIF

(Tagged Image Format) files, JPEG (Compliant), RAS (Sun Raster Images), TGA (Truevision Images), and so on, which may be opened and read by less specific.

3. ARCHAEOBOTANY

The morphological characterizations, performed after the finest sediments had been removed, evidenced the structures of seeds (profile, beak, raphe, chalaza, cell edges) and the pollens (air sack, exine, pore, aperture, measurement of polar and equatorial axis and automatic counting of pores) that help determine the proper taxonomic classification. The materials were then compared with a set of reference samples, taking into account that the carbonization process can alter a seed’s original profile and dimensions (biometric size). The preservation of macro and microremains of plants in archaeological sediments is due essentially to the fact that decomposing agents such as bacteria and fungi, which feed on organic macromolecules (especially glucides), are not present in carbonized materials. The combustion of seeds and fruit usually happens by chance, but may have occurred in an attempt to improve their qualities by toasting them in an oven or on hot slabs of stone. Probably the fastest way to eliminate the husks of wheat and barley grains was by heating them. Lightly toasting sour fruit (such as apples) can improve their taste or prepare them for other uses. Legumes (lentils, beans, peas and vetches) usually do not call for heat treatment, nor do huskless cereal grains. At Pyrgos, all the paleocarpologic remains were evidently carbonized in a fire that broke out in the room where the olive-oil press was located (SU G7L5), probably due to an earthquake repeatedly documented by differently sized fragments of huge oil containers (now restored) and by reduced-iron measurements made directly on the sediments of SUs G9L3, G9L4 and G9l7. The carbonization and fossilization undergone by the seeds in silt sediments (Lentini, 2005) altered their original biometric size. Accordingly, the only dimensions we measured were the length, width and thickness of each seed and the length of the tip (Di Vora & Castelletti, 1995). The length/width index in particular is considered a statistically significant parameter for the attribution of each seed (Castelletti *et al.*, , 1996). A seed is thought to belong to the wild species if the index is between 0.76 and 0.83, to the cultivated species if the index is between 0.33 and 0.44, and unidentifiable if the index is between 0.54 and 0.75 (Di Vora & Castelletti, 1995). These preliminary data on the first 41 seeds are not statistically significant, but they can be taken as a preliminary indication of the distribution of the various *Vitis* species at Pyrgos.

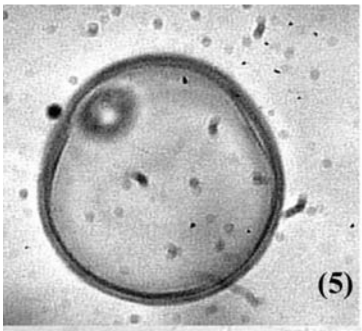


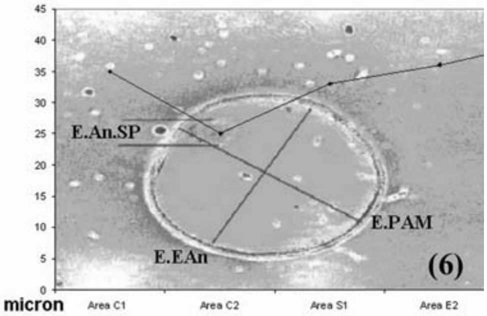
```
HOLE number   7 (nest level 2)

Area              2.00
Detect.area       2.00
Center of area    <201.50, 268.00>
Perimeter         2.828
Circularity 3.142
Length    2
Breadth   1
Orientation       0
Grey Weight       494
Opt. Weight       0.02781
Equi.circle 0.7979
Min Radius        0.5
Max Radius        0.5
Mean Radius       0.5
Convx Perim       2.828
Mean Feret Diameter          1.60
Mean intercept count 1.63
```

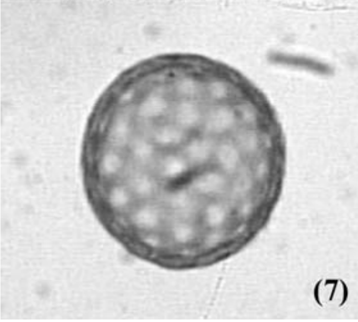
Figures 1,2,3, and 4 - A colour threshold and measurements of area (this is always less than equal to area), perimeter (a measurement is calibrated units of the length of the smoothed outer edge of digitised object), length (is the maximum chord length of the object regardless of orientation. There is calculated by an iterative process. First the canter of area is found, then the furthers point in the object boundary from this centre is determined, the the furthest boundary point from this point is found.) and breadth (is the projection of the object onto an ax) of carbonized seed of Vitis sp..

4. PALEOPALINOLOGY

The morphobiometric study of these pollen types was recently recast with the aid of an image analyser. Automatic counts and measurements of morphobiometric features (automatic measurement of polar, equatorial axis and counting of pores) (as proposed by S. T. Andersen) were made for *Cerealia* and the other Graminaceae. As regards the Fabaceae, meaning *Vicia* (vetch), Chenopoduaceae and *Pisum* (pea), reference was made to the parameters suggested by Moore & Webb (1978).







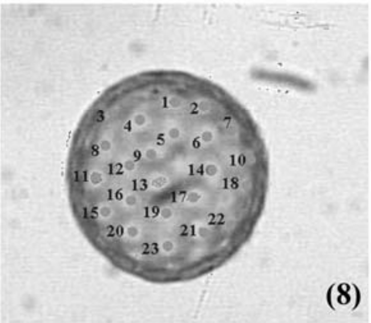
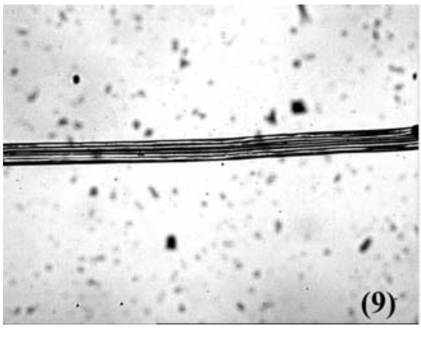


Figure 5 – PY05SUG9L4 - Monoporate pollen with distinct annulus, grain psilate (Cereal type); figure 6 – Measured parameters of longest dimension (Lemma: E.An.SP – E.PAM – E.E.An). The following formula are used for the derived measurements is Form Factor = 4π x Area / Perimiter2.; figure 7 - PY05SUG9L4 – Periporate grain of Chenopodiaceae, tectum without perforation. Numbers of porese usually higher then 50; figure 8 - Calculation of pores after modify the size in the binary image according to the relationship of pixel to other pixels.

5. TEXTILE FIBRES

Urena lobata, is a Malvaceae**,** with long, glossy (Garner, 1949), and fine filaments. It is used for the manufacturing of ropes and light textiles. In ancient Greece (Pekridou, 1992) a fiber was produced from the Malvaceae family. This fiber was always cited in literature with generic terms but never discovered in excavations. The discovery inside the loom weight in SU J6L5 of an *Urena lobata* fiber can thus be considered significant.



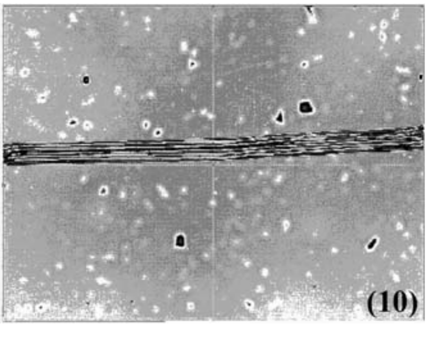
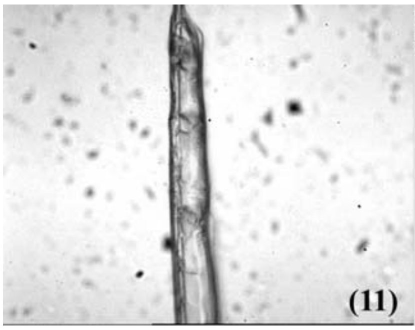


Figure 9 – SU J6L5 Fiber of Urena lobata. Figure 10 - Application of the technique of equalization with the generation a different colour levels for the characterization de single hairs vegetables that compose the fiber.

6. ASBESTOS FIBERS

Medium-large dimensions, flattened with a pointed extremity. It has a central canal with semi-diagonal septa that correspond to various discontinuous growths alternating with a secondary canal. The fibers can be free in a friable matrix or weakly bonded (Belgiorno & Lentini, 2005). It is almost always known for being easily spinnable and weaveable**,** and as the most fine and precious fibers of antiquity. It was called “live linen” or “Koapas linen” (Plinio il Vecchio) in the area of Cyprus, where it is obtained.



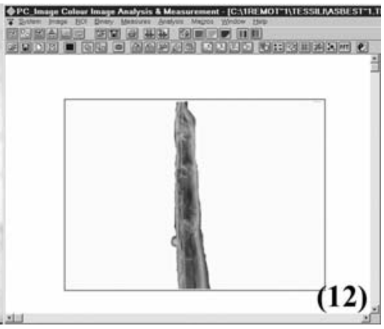
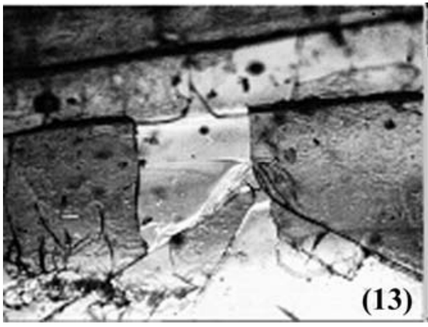

PC Image Colour Image Analysis & Measurement - [C:\1REMOT~1\TESSILI\ASBEST~1.TI
(12)

Figure 11 – Asbestos fiber with semi-diagonal septa. Figure 12 – LUT Operation, the difference filter takes the between the maximun and minimum values in the neighbourhood thus acting as an detector.

7. GLASS

In this way we were able to discover defects of homogeneity due to superimposition of layers in areas of different composition, as well as chemical homogeneous areas which had undergone a different thermic treatment, giving rise to visible streaks with a different degree of refraction to the surrounded area, knots, hair live streaks (due to further thermic treatment) and unevenness of the surface. Besides bubbles due the presence a gas (Lentini, 2004), were evident together with trapped condensation.



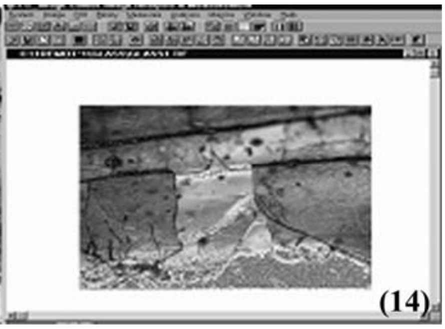
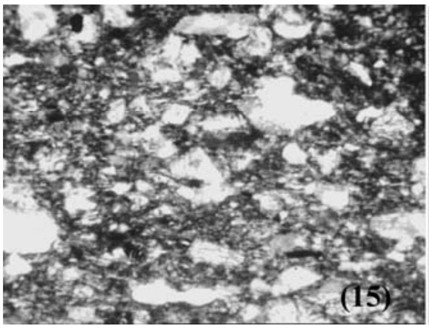


Figure 13 - The Devitrification Process , the amorphous substances with the time form in own structure of the crystallization nuclei, that they produce tensions and that they render the glasses ones in theirs with fragile. Figure 14 - The morphological operation for characterization the devitrification process, work on the bimary image by considering the pixels set in any neighbourhood and alter the image according to criteria based on these value.

8. POTTERY

The image analysis of the cross-section refers to two constituent components, i.e. the inorganic (including lithic materials) and the organic one (including vegetal microremains). For the study of porosities produced during firing, it’s more useful to work on thin cross-sections. The dimensional distribution of the lithic component is characteristic of a given pottery type and provides the means of discriminating the different pottery types of the site. Such a method of discrimination can also be used on a larger territorial scale.



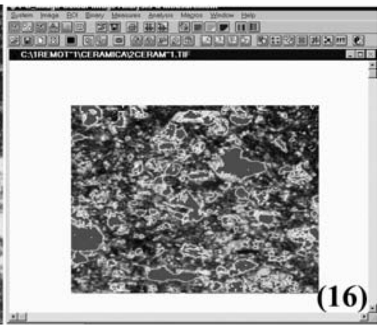


Figure 15/16 - Equalization of the image for the counting and the measurement of the lithic materials included ones.

9. REFERENCES

Andersen, S.Th., 1978-9. *Identification of Wild Grass Cereal Pollen,* Geological Survey of Denmark, 79 : 69-92.

Belgiorno, M.R. 2004. *Pyrgos Mavroraki <Advanced Technology in Bronze Age Cyprus>,* I, 45-47, CNR Bureau President's, Nicosia.

Belgiorno, M.R., Lentini, A., 2005. L'industria tessile del sito preistorico di Pyrgos - Mavroraki (Cipro), *Informatore Botanico Italiano*, 37, 1 : 894-895.

Berns, R. S. 1999. *Challenges for Colour Science in Multimedia Imaging Systems*, in Mac Donald L. and Luo R., eds., *Colour Imaging: Vision and Technology*, John Wiley & Sons, England, 99-127.

Castelletti L., Castiglioni E., Cottini M. e Di Vora A., 1996. Analisi morfometrica dei vinaccioli di vite (*Vitis vinifera* L.) provenienti da scavi archeologici, XIII International Congress of Prehistoric and Protohistoric Sciences, Forlì, Italia - 8/14 September 1996 - Colloquia 3, *Palaeoecolog,* 11-24.

Findlay, F. 1995. *Image Analysis and Measurement*, Vol. 1, Foster Findlay Associates Ltd, London.

Garner, W., 1949. *Textile Laboratory Manual*, Vol.1, Publishing Company, London.

Grieson, P., 1986. *The Color Cauldron*, Publishing Company, London.

Hanbury, A., Serra, J. 2001. Mathematical morphology in the CIELAB space, *Image Anal. Stereol.*, 21 (3): 201-206.

Lentini A. 2004. 'Sul contenuto di un'ampolla di vetro di epoca Romana proveniente da Scafati, (Salerno)', *Atti del III Congresso Nazionale di Archeometria*, a cura di C. D'Amico, vol. III, 363-369, Pàtron Editore, Bologna.

Lentini, A. 2005. Archaeobotany brewing and winemaking in Mediterranean basin and TransCaucasus area, In: Flourentzos P., Belgiorno M.R. and Lentini A., *Cyprus in the Prehistory of Wine*, MAE Ambasciata d'Italia a Nicosia, 11-16.

Moore, P.D., Webb, J.A., Collison, M.E. 1997. *Pollen Analysis*, Blacwell Science Ltd, London.

Pekridou Gorechki, A. 1992. *Come Vestivano i Greci*, Vol. I, 28-cit., *Teofrasto e Plinio*, Rusconi, Milano.

Hierapolis of Phrygia Project: integration of archaeological survey and remote sensing data

G. Scardozzi

CNR-IBAM, Italian National Research Council – Institute for Archaeological and Monumental Heritage, Strada per Monteroni c/o Campus Universitario, 73100 Lecce (Italy); g.scardozzi@ibam.cnr.it

Keywords: Landscape Archaeology, High Resolution Images, Survey, DEM, Cartography.

ABSTRACT:
This paper concerns research activities of Institute for Archaeological and Monumental Heritage of the Italian National Research Council (*CNR-IBAM*) finalized to the reconstruction of ancient urban layout of Hierapolis of Phrygia (Turkey), and to the study of its territory. Researches, started since 2003 in cooperation with Italian Archaeological Mission, are based on different study methodologies, as systematic archaeological survey, geophysical prospecting and processing, analysis and interpretation of high resolution satellite images. In integration to the few aerial photos available, satellite images of QuickBird-2 and Ikonos-2 are processed and used first of all to find traces and anomalies linked to archaeological buried elements; very interesting was the comparison with high and middle resolution images of American spy satellites Corona and Hexagon taken during 1960s and 1970s, that allowed to discover archaeological elements nowadays not visible in areas heavily changed. In absence of up-to-date maps with a good scale for archaeological survey, satellite images were orthorectified and used as maps for the studies on the ancient territory of Hierapolis, also in the field work. The ortho-images and the numerical derived maps, with technical specification own of maps for archaeological research in scale 1:10000, become layers of Hierapolis and its territory WebGIS.

Since 2003, Institute for Archaeological and Monumental Heritage of the Italian National Research Council (*CNR-IBAM*) has conducted archaeological researches in Hierapolis of Phrygia (Pamukkale, south-west Turkey), in cooperation with Italian Archaeological Mission. The researches (just in progress) are finalized to the reconstruction of ancient urban layout of the city and to the study of ancient topography and settlement of its territory. They are based on different study methodologies: systematic archaeological survey, geophysical prospecting (magnetometric survey and Ground Penetrating Radar) and processing, analysis and interpretation of high resolution satellite images. In integration to the aerial photos available, especially oblique from the helicopter and aerostatic balloon, a few panchromatic and multispectral satellite images (QuickBird-2 of the years 2002, 2003, 2005, 2007, and Ikonos-2 of 2004; with ground resolutions re-sampled to 0.60 and 1 m in panchromatic mode and 2.40 and 4 m in multispectral mode), are processed and used first of all to find traces and anomalies linked to archaeological buried elements, always verified on ground (D'Andria *et al.*, 2008, 25-30).

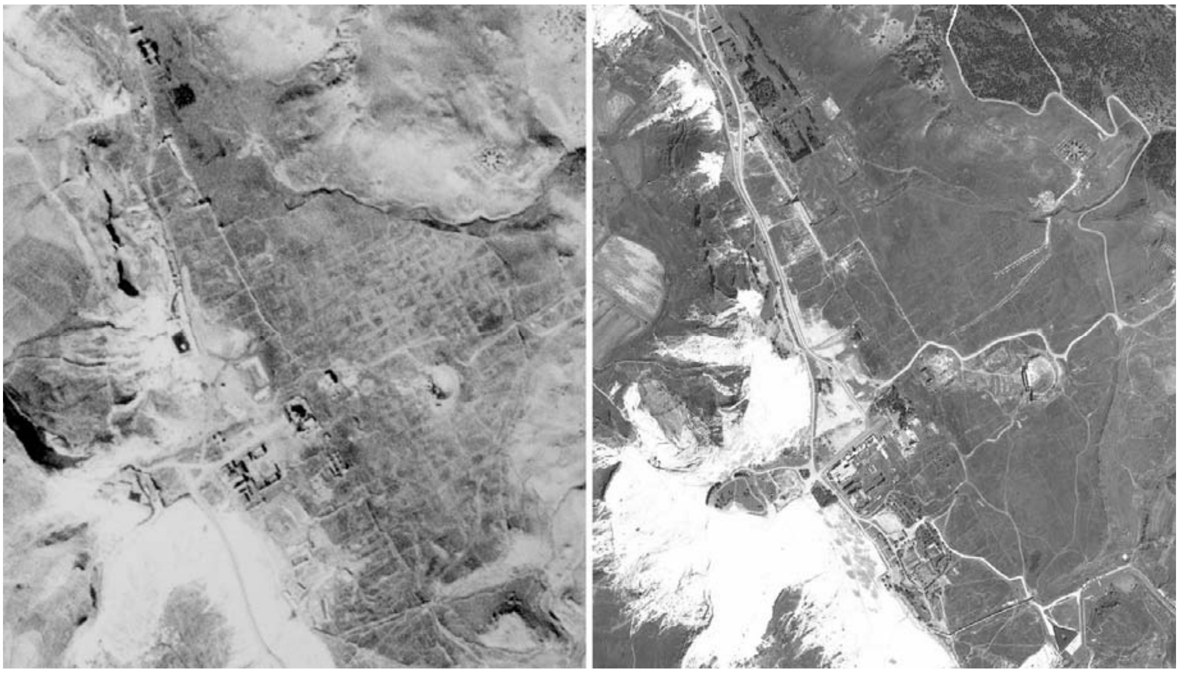
Thanks to their high spatial resolution, satellite images are particularly adapt to be used in detailed archaeological surveys aiming at the study of contexts of limited extension (urban areas, single monumental sites and evidences) and, for this reason, they have been used in each phase of the research: from the activities on the field to the data elaboration and management up to the presentation of the results, giving an important contribution to the surveys; reading and interpretation of the traces and anomalies concerning buried or semi-buried archaeological elements, constantly verified and compared to the available aerial shots, have allowed the identification and the spatial characterization of several archaeological evidences. Images have also allowed the detection of various palaeo-environmental elements, contributing to the reconstruction of the ancient landscape; as regards objects or visible archaeological sites, images have been used in order to document and contextualize.

Thanks to the characteristics of the satellite images acquired in multispectral mode, in which the measured radiation is divided in four bands including the spectrum of the visible and near infra-red, it was possible to individuate and highlight, in a better way, archaeological and palaeo-environmental traces and anomalies. For this reason, elaborations like the *colour composite RGB* of the original bands have been created (3-2-1, 4-3-2, 4-3-1, 4-2-1) together with the calculation of those indexes which allow to show the presence, the kind and the status of the vegetation and its different growth connected with buried presences (Lasaponara, Masini, Scardozzi 2007): the *Normalized Difference Vegetation Index* (NDVI) and the *Tasselled Cap Transformation* (TCT) have been used. Moreover, a "fusion" between the panchromatic datum and the multispectral elaborations has been made, in order to integrate the high spatial resolution of the first kind of image and the spectral information acquired in the various bands with a lower spatial resolution; to this aim some techniques of *data fusion* have been tested, like *HSV Sharpening, Colour Normalized (Brovey)*

Sharpening, Principal Components Spectral Sharpening, getting new *pan-sharpened* images in real colours or false colour, with a high spatial resolution (0.70 m).

The *Gram-Schmidt Spectral Sharpening* and Zhang's algorithm have emerged as the two mostly accurate methods with a much higher relation between high spectral quality and maintenance of the high spatial resolution. Moreover, if you consider the different nature of the achievable information in the various bands, the red and near infra-red channels have resulted the most appropriate for the identification and the definition of the archaeological traces; in particular, the near infra-red band is the one that has better rendered the information about phenomena of stress of vegetation determined by the ancient buried or semi-buried remains, highlighting mostly the traces connected with the non homogeneous growth of the grassy blanket. Therefore, high resolution satellite images are used to discover new archaeological evidences, even of small dimensions, and for their contextualization in relation with the already well-known ones. They are a fundamental supporting instrument for the field work, providing a good amount of data and indications for the excavation activities and archaeological survey.

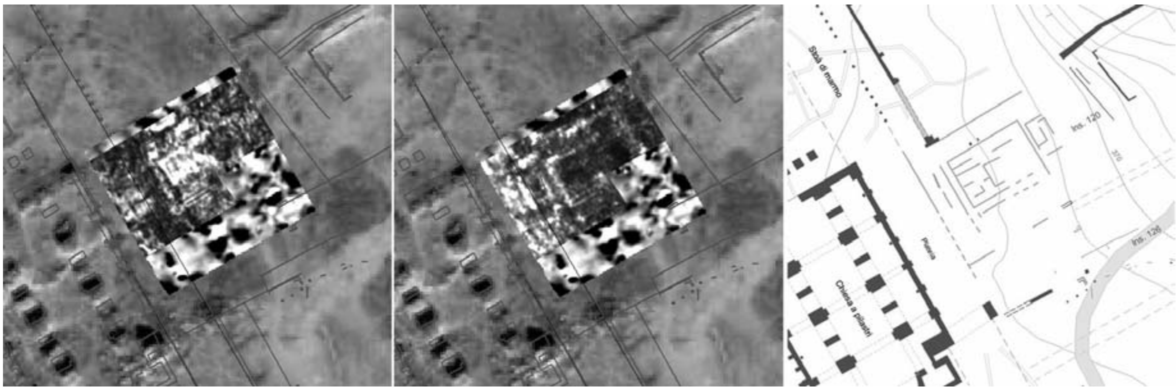
During the research activities on ground, it was led a constant check of the traces (damp-marks, grass, weed and crop marks, soil sites) and anomalies found in the images, in order to specify their real pertinence to archaeological elements, the interpretation and, if possible, also the chronology, avoiding misunderstandings and mistakes. Data obtained by the comparison and the integration with the aerial oblique photos were very important too, because they were very useful for the documentation of the archaeological areas, helping to understand some topographical situations and the articulation of monumental sites.



Figures 1/2. Hierapolis: satellite photo taken in 4th of February 1968 by Corona KH-4A and pan-sharpened (Zhang's algorithm) satellite image taken in 10th of March 2007 by QuickBird-2, with false colours infra-red (bands 4-3-2): a lot of traces and anomalies of the urban layout are visible.

Since 2007, in order to recover further knowledge about those less well-known sectors of the urban area, archaeological surveys and remote sensing data have been also integrated with geo-magnetic surveys and with the use of the Ground Penetrating Radar (GPR); this methodological and multi-disciplinary approach, based on the integration of different technologies of remote sensing, was particularly necessary in some areas of the city, where colluvial and alluvial sediments and a thick layer of limestone, which covers the western side of Hierapolis, avoided to discover the articulation of the urban layout. Geo-physical surveys completed and tested in various points with different geo-morphological characteristics have allowed to individuate traces of roads and masonry structures buried under a thick depository of even 3-4 m; of fundamental importance for their appropriate interpretation was the integration with the already acquired information, thanks to the georeferencing in the archaeological plan of the city, the comparison with the collected data during the archaeological surveys and the analysis of the satellite images. The results of the geo-physical surveys too, that are anomalies regarding ancient remains, were merged in the numeric cartography of Hierapolis, enriching the heterogeneous archaeological thematic material.

In the QuickBird-2 satellite images, used for the research project, it is noticed a poor visibility of the archaeological traces highlighted by the micro-relief (shadow sites), because of the impossibility of the stereoscopic reading; in fact, even if a lot of images were acquired in the morning, with the sun still down on the horizon, so that many height differences result to be highlighted by long shadows, it is not possible to appreciate the slightest altimetric variations anyway. At the beginning, in order to avoid this kind of difficulty, some anaglyphs were processed, experimentally; in fact, they were obtained by a duplication of the same image, with an optical artifice that allows a quick perception of the third dimension, without achieving a real stereoscopy. Moreover, digital models of the ground, with a middle-high resolution, have been processed and they base on SRTM data and on a stereo pair taken by ASTER sensor. On these data, both the panchromatic images and the multispectral elaborations have been geo-referenced, in order to associate the archaeological traces to the morphology of the ground and to study the territory in third dimension. A stereo-pair, taken by the satellite Ikonos-2 in 2004, have been also used; they have been processed to get epipolars panchromatic images. From these images, using automatic techniques of auto-correlation, typical of the digital photogrammetry, an high-resolution DEM was extracted; it was drapped with the panchromatic satellite images and with the real colours and false infra-red colour pan-sharpened images. Moreover, it has been possible to display an anaglyphs of the epipolar images that provided a real stereoscopy in which the micro-relief seems to be strongly exalted; even the slightest orographic variation can be caught, with the possibility to measure differences in elevation.



Figures 3/4/5. Geo-physical survey in the central area of Hierapolis, that have highlighted anomalies linked to a buried edifice (a temple?) along the plateia, where on surface are not present any evidence: are visible the results of the GPR at deep of 0.50 and 1.50 m (georeferenced with the QuickBird-2 satellite image and the archaeological plan of the city), and the vectorialization of these results on the new archaeological map of Hierapolis (D'Andria, Scardozzi, Spanò 2008).

3D models of the ground, on which satellite images are drapped, are particularly useful, not only for the study of the territory, but also for the presentation of the results of researches, both with static images and simulations of flight; in fact, georeferencing on them the archaeological evidences taken into consideration, you have the possibility to show the territory in its real orographic formation and to display, in their proper altimetric position, the ancient remains and the routes of aqueducts and roads. For a contextualization of Hierapolis in its territory and a study of this last one to a lower detail scale, satellite images, with a middle-low spatial resolution are used, that are a 2004 ASTER stereo-pair, acquired in the near infra-red, with a 15 m resolution on the ground, 1986 SPOT-1 images with a maximum of geometric resolution of 10 m and the ones acquired by satellites Landsat 4 and 5 TM and Landsat 7 ETM+ from 1990 to 2003, available in NASA World Wind; these last ones are real colours or false colour images, with spatial resolutions between 15 and 30 m (GeoCover 1990, GeoCover 2000, I-Cubed, OnEarth).

Besides recovering a multi-resolution documentation (middle-low, high and highest), it is very important to have the use of multi-temporal images, limited not only to the last years, but also to some decade ago; for this reason, during the researches, reading and interpretation of "historical" satellite images were very useful, that is panchromatic aerial photographs taken by American reconnaissance satellites in the 1960s and 1970s. As regards Hierapolis and its territory, some images, dating back to a period between 1961 and 1980, have been acquired with different spatial resolutions; from these images it is possible to get many data both on urban and extra-urban areas, changed, in the last decades, because of the urbanization and the mechanized agriculture; it deals with photographic images taken by the satellites Corona KH-2 and KH-3 in 1961 (geometric resolution 7.5 m), Corona KH-4A in 1968 (geometric resolution 2.70 m) and Hexagon KH-9 in the years 1973, 1976, 1979 and 1980 (geometric resolution between 6 and 9 m). The systematic archaeological surveys, together with the constant analysis of the satellite and aerial photos and the verify on the ground of the traces, have allowed to recover a lot of data about the urban layout of Hierapolis, previously not systematically verified; these data are included in the numerical cartography of the town, elaborated to scale 1:1000 by the architects of the Polytechnic Institute in Torino (D'Andria et al., 2008, 1-16).

Sometimes, the new data acquired from the archaeological surveys and from satellite and ground remote sensing had directed the strategies of the archaeological excavations. The discovery of the processional route to the Martyrion of St. Philip is surely the principal example of this methodology of research; the traces and anomalies linked to the route were firstly recognized in the satellite images and after verified on the ground; finally, the ancient structures were excavated.

For the research in the territory of Hierapolis, satellite images had replaced aerial photos and integrated also cartographies used in the field work and in the GIS. In fact, while about the urban area and the necropolises is available a numeric cartography on a large scale, instead about the territory that in ancient times were under the control of the city is available only raster cartographies on a scale 1:25000, update in 1990s and little detailed, therefore poorly usable particularly in the field work. So, space-maps of some sectors of the territory have been created, with tolerances of cartographies on a scale between 1:10000 and 1:5000, thanks the orthorectify of satellite images with the use of DEMs and *Ground Control Points* (GCP) and *Check Points* (CP) taken with GPS; cartographies for archaeological research have been also produced (in the tolerances of a 1:10000 scale) and vectorial elements (modern topography, hydrology, archaeological evidences and traces, etc.) have been also extracted from high resolution satellite images (see Di Giacomo, Ditaranto, Scardozzi in this volume).

During researches in the territory of Hierapolis, geo-referencing satellite images, space-maps and numeric cartography aimed to archaeological research and created from satellite images, along with topographic map at middle-scale available (Harita Genel Komutanliği, on a scale 1:25000), were used during work on the ground within a system, called *Ulixes*. Especially, it is created to provide a support to archaeological survey, speeding work on the ground and positioning archaeological precenses and data; system allows to navigate on cartographies (vectorial and raster), vertical aerial photos and high-resolution satellite images visualized on a Tablet PC linked to a GPS receiver with metric precision (see Di Giacomo, Di Giacomo, Scardozzi in this volume).

Finally, integration between archaeological survey, satellite remote sensing data and ground remote sensing data was very important for reconstruction of the ancient urban layout of Hierapolis and to create the archaeological map of territory. So, integration between different methodologies and technologies was fundamental in the Hierapolis of Phrygia Project for the knowledge of city plan and its transformations particularly in the Imperial Roman period and during the Byzantine age; moreover, in its territory were reconstructed aqueducts and ancient roads, and were identified necropolises, farms, marble and travertine quarries, sanctuaries, rural settlements and villages that were under the authority of the city (Scardozzi 2007).

ACKNOWLEDGEMENTS

The archaeological surveys and the researches on the ancient topography of Hierapolis and its territory are possible thanks to the constant support of Prof. Francesco D'Andria, Director of the Italian Archaeological Mission and of CNR-IBAM; special thanks also go to Doctors Laura Castrianni, Giacomo Di Giacomo and Imma Ditaranto, that work in the researches in Hierapolis of Phrygia and in the processing of the satellite images. Geo-physical surveys are realized from 2007 by Doctors S. Giese and C. Hübner of the company GGH (Giese, Grubert & Hübner Gbr.) of Freeburg.

REFERENCES

D'Andria, F., Scardozzi, G., Spanò, A. 2008. *Atlante di Hierapolis di Frigia,* Istanbul.

Lasaponara, R., Masini, N., Scardozzi, G. 2007, Immagini satellitari ad alta risoluzione e ricerca archeologica: applicazioni e casi di studio con riprese pancromatiche e multispettrali di QuickBird, *Archeologia e Calcolatori*, 18, 187-227.

Scardozzi, G. 2007. Remote sensing and archaeological survey in the Hierapolis of Phrygia territory, Turkey, in *Remote Sensing for Environmental Monitoring, GIS Applications, and Geology*, Conference 6749 "Remote Sensing and Archaeology" (Florence, 17-20 September 2007) - Proceedings of SPIE Europe Remote Sensing, vol. 6749, 674904/1-12.

New perspectives for archaeological research by satellite imagery in Cahuachi (Peru)

N. Masini[1] , R. Lasaponara[2], G. Orefici[3], R. Coluzzi[2]

1 CNR, Institute of Archaeological and Architectural Heritage, C.da S. Loja, 85050 Tito Scalo,Italy; E-mail: n.masini@ibam.cnr.it

2 CNR, Institute of Environmental Analysis, C.da S. Loja, 85050 Tito Scalo, Italy; E-mail: lasaponara@imaa.cnr.it

3 Centro de Estudios Arqueológicos Precolombinos (CEAP), Nasca, Peru

Keywords: satellite, archaeology, Cahuachi, feature extraction, Nasca, Peru

ABSTRACT.

Ongoing archaeological excavations performed during the last two decades in the Ceremonial Centre of Cahuachi (Nasca, Peru), have been unearthing remarkable examples of adobe monuments of the Paracas and Nasca civilizations. The high cultural value of the territory needs to enlarge the area to investigate. In this context the remote sensing could be a valuable data source, but the detection of buriedd adobe structures is quite difficult to be performed due to the low contrast generally existing between adobe, that is sun-dried earth, and the background subsoil.

This paper is focused on the evaluation of the capability of satellite Very High Resolution (VHR) images for the identification and mapping of archaeological adobe structures.

The investigation was performed on a cultivated strip, crossed by the Nasca river, near the unearthed temples of Cahuachi. In this area, the different properties between possible adobe structures, and the surrounding earth material caused variations in moisture content and growth of plants, detected by the multispectral satellite imagery, thus providing features, referable to pyramid.

This discovery can open new perspectives for the archaeological research in Cahuachi territory and for the remote identification of buried adobe structures.

1 INTRODUCTION

The identification of buried archaeological adobe structures by not invasive techniques is an issue of high cultural, scientific and technical interest, due to the long and diffuse use of this material throughout the world.

Such issue is complex to be addressed from any type of remote sensing techniques due to the low contrast generally existing between adobe, that is sun-dried earth material, and the background subsoil. The capability of detecting this material is still more difficult in desolate environment, such as in Cahuachi (Southern Peru) herein investigated, because of the lack of moisture and vegetation which typically reveal features of archaeological interest.

In Cahuachi, such difficulty is confirmed by the comparison between aerial images taken before and after the archaeological excavations (Orefici, 1993). In particular, this comparison put in evidence three important facts: (i) the buried adobe structures are generally not visible from an aerial view; (ii) shallow structures may be detectable thanks to the small shadow produced on the ground; (iii) surface remains are easier identifiable due to the high contrast in brightness between the clay of the surface adobe walls and the surrounding alluvial deposits which cover the area.

More possibilities in collecting information are expected for vegetated areas where the moisture and the vegetation could play an important role in revealing archaeological features, related not only to surface and shallow structures but also to buried remains.

This paper is focused on the evaluation of the capability of satellite Very High Resolution (VHR) images for the identification and mapping of archaeological adobe structures. The investigation was performed on a cultivated strip, crossed by the Nasca river, near the unearthed temples of Cahuachi.

2 STUDY AREA.

Cahuachi is situated at an elevation of 365 m a.s.l. in the South Nasca Region. This region is classified as Pre-Montane desert formation; geologically, it is included between the Ica-Nasca Depression and the Andean foothills: The tectonic depression is located from approximately 350-450 m in elevation and it consists of Quaternary sedimentary rock formations that are riverine and riverine alluvial. The Andean foothills, above 450 m in elevation, are composed primarily of the Jurassic and Cretaceo formations, consisting of clastic sedimentary rock with cretaceous plutonic intrusions of graniodiorites and gabbrodiorites (Montoya *et al.*, 1994).

The climate is hot and arid with very little measurable rainfall recorded each year. From the hydrographical point of view the region is characterized primarily by influent streams which flow for a few weeks in the wet season thanks to runoff from rains in the highlands (ONERN, 1971).

Despite these difficult climatic conditions, one of the most important Pre-Inca civilizations, developed and flourished in this region. It is the Nasca civilization well know for the famous geogliphs and lines " inscribed in the World Heritage List and for fine material culture, such as textiles and polychrome pottery (Vaughn & Neff, 2004; Vaughn & Van Gijseghem, 2007).

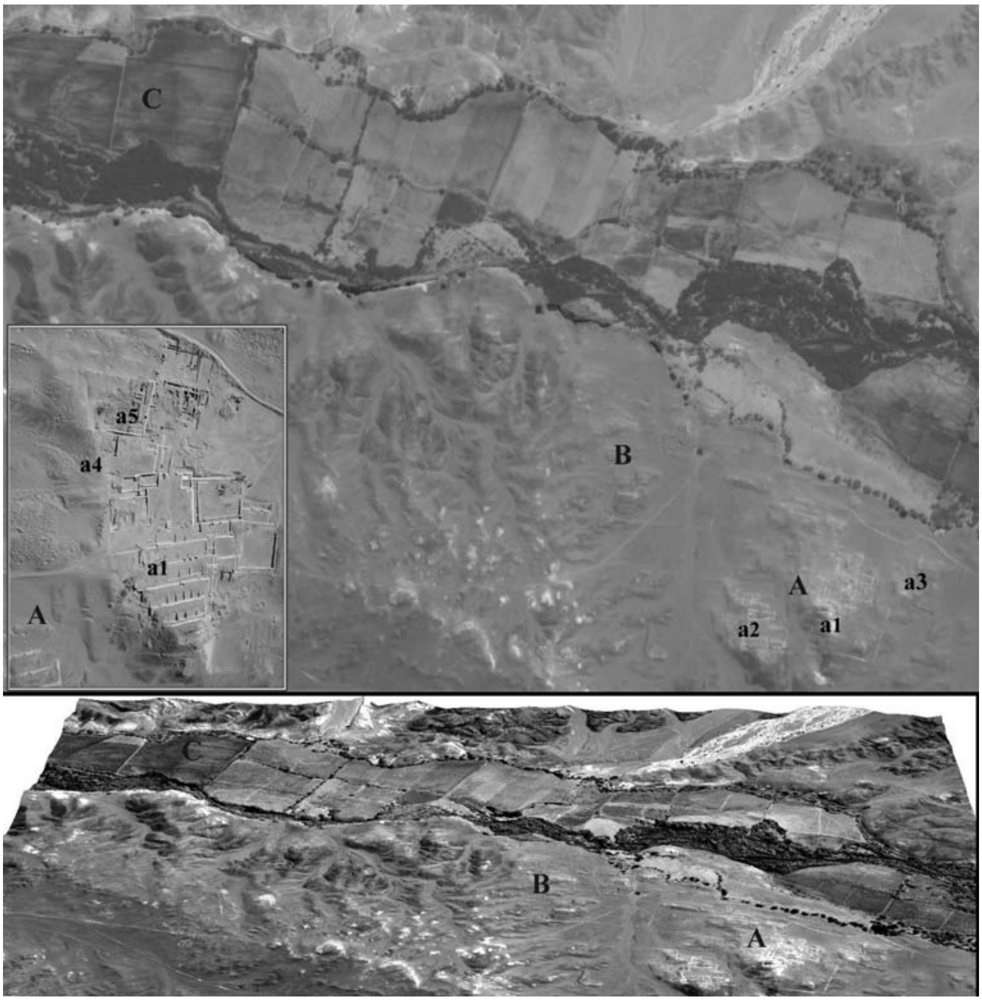


Figure 1. QuickBird RGB (R=red, G=green B=blue) composition (upper) and 3d surface of Cahuachi (lower). Letters A and B denote the sectors where the archaeological investigations have been performed. The excavations and trials have been only focused on sector A (see zoom in red box of 2008 aerial image) and in particular in the Gran Piramide (a1), Grande Templo (a2), Monticulo (a3), Templo de Naranja (a4), Templo del Escalonado (a5). The sector C object of investigation is locate at NW of the excavated area.

Historically, this region and in particular, the drainage basin of Rio Grande has been populated by sedentary groups at least since the Formative Period (Initial Period, 1800-800 BC; Paracas culture, 800-200 BC). In the Early Intermediate Period (200 BC-600 AD) the region flourished under the Nasca Culture, during Cahuachi was founded and developed.

Cahuachi is believed to have been an important ceremonial centre (Silverman 1993; Orefici 1992; Orefici 1993) which served as a place of pilgrimage for the population living in the basin of Rio Grande. The archaeological evidences spread out on a large desolate area sited on the left of the river, characterized by about forty mounds, along with 3 and 4-sided enclosures. Some of them have been excavated by an Italian-

Peruvian Mission directed by G. Orefici (see sector A, figure 1). Other have been only surveyed (see figure 1, sector B).
Up to now, the mission have completely unearthed and restored a huge asymmetrical Pyramid (known as *Grande Piramide*; see a1 in figure 1). Whereas, a terraced temple (*Templo del Escalonado*; a5, figure 1) and a smaller pyramid (*Templo de Naranja*, a4, figure 1) are in advanced state of excavation. Sector A also includes another mound (*Monticulo*; a3 in figure 1), that has been partially unearthed and a terraced mound not still excavated (*Grande Templo*; figure 1, a2).

The results of archaeological excavations allowed us to identify five building historical phases (400 B.C. – 400 A.D.), during which architectural types and building characteristics have been changing, thus reflecting the functional and cultural evolution of the site (Orefici & Drusini, 2003), which was at the beginning a sort of sanctuary or Huaca. Then it became a ceremonial centre, later the Theocratic Capital of the Nasca state, and finally (300-400 A.D.), it was abandoned and covered with sand of the desert, after some destructive seismic and flash flood events.
A still unexplored area is located on a near cultivated strip around the river, where important information can be extracted and recorded by means of remote sensing techniques.

3 SATELLITE BASED ANALYSIS

3.1 *Satellite data and processing*

QuickBird is the commercial satellite that provides the highest spatial resolution of multispectral images. It has panchromatic and multispectral sensors with resolutions of 61-72cm and 2.44-2.88m, respectively, depending upon the off-nadir viewing angle (0-25 degrees). The panchromatic sensor collects information at the visible and near infrared wavelengths and has a bandwidth of 450 – 900 nm. The multispectral sensor acquires data in four spectral bands from blue to near infrared (NIR).
The QB data used for this study (Catalog ID 90100100153B9E00) were acquired on the 25th March 2005 at around 15 with an off nadir view angle of 11.9 degrees.
The identification of archaeological features related to surface and buried adobe structures was performed considering both single spectral channels and numerical combinations. All of them were first investigated individually and then combined by using a data fusion algorithm in order to integrate the geometric detail of panchromatic and the spectral information of the multispectral images.
The benefits achievable from fusion algorithms have been assessed in a number of different application fields and also specifically in the case of satellite –based detection of archaeological remains (Lasaponara & Masini, 2006a).
In order to enhance the contrast between the archaeological features and the surrounding area spectral indices were adopted. They are generally computed by a linear combination of different spectral bands in order to obtain quantitative measures of surface properties. Spectral indices, attempt to quantify surface properties such as brightness, moisture, biomass cover, or vegetative vigour. Usually, the numerator band is chosen in which the material is highly reflective, whereas the denominator is a band covering an absorption feature for that material. In particular, vegetation indices are mainly derived as a ratio between near-infrared and red reflectance.
The widely used index is the Normalized Difference Vegetation index (NDVI) obtained by using formula 1:

$$NDVI=(\rho NIR-\rho RED)/(\rho NIR+\rho RED) \qquad (1)$$

The NDVI operates by contrasting intense chlorophyll pigment absorption in the red against the high reflectance of leaf mesophyll in the near infrared. High values of the vegetation index identify pixels covered by substantial proportions of healthy vegetation, whilst disease or stressed vegetation exhibits lower NDVI values.
The NDVI has been successfully used in archaeological applications to enhance crop marks for both homogeneous vegetation covers and sparse herbaceous plants (Lasaponara & Masini, 2006b) for satellite images acquired during different period of the year spring to summer, characterized by green or dried vegetation respectively.

3.2 *Satellite based results*

The investigation was performed on a test area, named sector C (figure 1), located at about 1,6-1,8 km Nortwest from the excavated area. It was covered by plants and grass at the time of satellite image acquisition. The river is located at about 200 mt of test area and it supplies enough water for the cultivations. Variations in vegetation and moisture content revealed themselves as important indicators on the presence of cultural features (see figure 2).
In the panchromatic image of figure 2a, it is possible to observe subtle anomalies refer to a quadrangular structure. The quandrangle is crossed by a landmark which divides the surface in two parts having triangular

shape. The left triangle one is more vegetated than the right one, as confirmed by the higher NDVI value observed (see table 1).

Figure 2b shows the NIR data fusion product which only evidences the external perimeter of the quadrangular structure. Whereas the internal anomalies are visible only the left part of the quadrangle, due to the presence of more healthy vegetation as confirmed by the NDVI values (see table 1)

Compared to the panchromatic and NIR images, a significant improvement has been obtained by the red data fusion product (figure 2c) which clearly puts in evidence a spatial articulation of the features which has been thought related to a buried terraced structure. The difference in permeability between the more compact buried adobe structures respect to the surrounding could have favoured a difference in moisture content well detectable by the red band.

Figure 2d shows NDVI map which allowed us to obtain the best contrast of the marks. Both the external border of the quadrangle and the internal rectilinear marks are well visible.

Figure 2e shows the RGB composition (R=red, G=pan, B=NDVI). It provided a more detailed visualization and spatial characterization of the features. In particular, the rectilinear anomalies (see figure 2f) compose four degrading terraces which suggest a truncated pyramid, whose asymmetric shape calls to mind the *Grande Piramide*. The base has dimensions about 90 x 100 m. The total area at about 9000 sqm is less than the *Gran Piramide* (11.5000 sqm), greater than *Monticulo* (5.500 sqm) and similar to the *Grande Templo* (about 9.500 sqm).

Considering the morphological structure of the detected features and the dimension comparable to other unearthed monuments, it is reasonable to think that the performed investigation allowed us to discover a buried pyramid previously unknown. This discovery opens new perspectives for archaeological research in the Cahuachi territory.

NDVI value	Quadrangular area		Features	
	left	right	left	Right
mean	0,3	0,25	0,36	0,24
min	0,16	0,007	0,29	0,14
max	0,54	0,5	0,47	0,4
dev.st	0,0518	0,0551	0,0337	0,0464

Table 1. NDVI values observed for the features and the areas respectively on the left and the right side of the quadrangle.

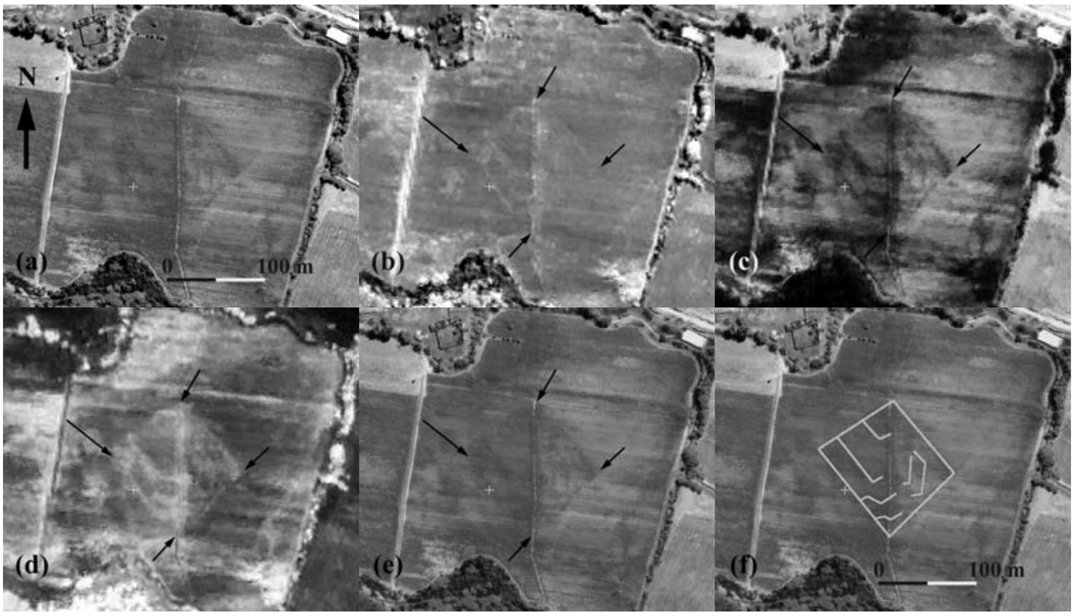


Figure 2. QuickBird imagery of test area: (a) panchromatic; (b) NIR data fusion product; (c) red datafusion product; (d) NDVI map; (e) RGB composition (R=red, G=pan; B=NDVI); (f) identification of marks related to a buried asymmetrical pyramid

4. CONCLUSION.

The low contrast existing between the adobe structures and the background soil makes difficult its detection by any type of remote sensing technique, especially for arid climatic conditions.

Such issue is an exciting challenge for its scientific and technical implications as well as for the exceptional cultural value of several adobe monuments built during the centuries throughout the world.

The results we obtained in Cahuachi pointed out the capability of multispectral very high resolution satellite imagery in detecting marks referable to buried adobe archaeological structures. In this area, the different permeability properties between possible adobe structures, mainly composed of clayey silt with low fractions of sand, and the surrounding earth material (in large part alluvial deposit) could have favoured different water absorption behaviors.

In this case, the different moisture content and differential growth of plants provided features, referable to a huge pyramid. These exciting results can open new perspectives for the archaeological research in Cahuachi and for the detection of buried adobe monuments.

5. REFERENCES

Lasaponara, R., Masini, N. 2006a. Performance evaluation of data fusion algorithms for the detection of archaeological features by using satellite QuickBird data, in Campana, S., Forte, M., *From space to place*, (Eds.), Proceedings of 2nd International Conference on Remote Sensing in Archaeology (Rome, December 4-7, 2006), BAR International Series : 13-20.

Lasaponara, R., Masini, N. 2006b. Identification of archaeological buried remains based on Normalized Difference Vegetation Index (NDVI) from Quickbird satellite data, *IEE Geoscience and Remote Sensing Letters*, 3 (3) : 325-328

Montoya, M., Gracìa, W., Caidas, J. 1994. *Geologìa de los Quadrangulos de Lomitas, Palpa, Nasca y Puquio*, INGGEMET (Istituto Geologico Minero y Metallurgico), Lima.

ONERN 1971. Inventario, *Evaluaciòn, y Uso racional de los recursos Naturales de la Costa: Cuencas de los Rìos san Juan (Chincha) y Toparà*, ONERN, Lima.

Orefici, G. 1992. *Nasca. Archeologia per una ricostruzione storica*, Jaca Book.

Orefici, G. 1993. *Nasca: Arte e società del popolo dei geoglifi*, Jaca Book, Milano.

Orefici, G., Drusini, A. 2003. *Nasca: Hìpotesis y Evidencias de su Desarrollo Cultural*, Centro Italiano Studi e Ricerche Archeologiche Precolombiane, Brescia.

Silverman, H.: Cahuachi in the Ancient Nasca World, University Of Iowa Press, 1993.

Vaughn, K.J., Neff, H. 2004. Tracing the clay source of Nasca polychrome pottery: results from a preliminary raw material survey, *Journal of Archaeological Science*, 31 : 1577-1586.

Vaughn, K.J., Van Gijseghem, H. 2007, A compositional perspective on the origins of the "Nasca cult" at Cahuachi, *Journal of Archaeological Science*, 34 : 814-822

Indices

Keyword Index

3D 99, 155, 239, 243, 253, 265, 315, 321, 369
3D GPR 155
3D Scanning 243
Aerial Archaeology 47, 51, 59,79
Aerial Photography 37, 55, 79, 103, 195, 275, 329
Aerial Reconnaissance 373
Airborne Laser Scanning 113
Ancient Irrigation 401
Ancient Land Division 405
Ancient Landscapes 63
Ancient Marbles 355
Angkor (Cambodia) 23
Apulia. 355
Aquileia (Italy) 85
Archaeobotany 419
Archaeological Aero-Topography 67
Archaeological Air-Survey 63
Archaeological Documentation 347
Archaeological Excavation 125
Archaeological Maps 275
Archaeological Modelling 397
Archaeological Park 415
Archaeological Remains 179
Archaeometallurgy 177
ARP 201
ASTER 23, 97
ATLAS 271
Augering 143
AVIRIS 271
Badami Site 265
Balloon 55
Basilicata 351
Bias 47
Bones 135
Bronze Age Burial Mounds 143
Buried Archaeological Structures 75
Burmese Urban Archaeological Site 401
Cahuachi (Perù) 213, 429
Cartography 41, 425
Castel-Minier 177
Chan Chan 415
Change Detection 313
Climate 393
Computer Graphics 261
Conflict Archaeology 59
Contextualisation 47
Contrast Enhancement 17
CORONA 275, 379
Cost Surface Analysis 297
Costanziaco 37
Crack Detection 185
CRIS 271
Crop Marks 17, 373
Cultural Heritage 207, 285, 321, 355
Cultural Heritage Management 347, 397
Damage Pattern 359
Data Acquisition 243
Data Capture 297
Data Fusion 31, 305
Desktop Virtual Reality (DVR) 257
Developments 51
Differential Magnetic 201
Digital Elevation Model (DEM) 27, 41, 113,325, 425
Digital Photogrammetry 253, 301, 313
Distance Visiting 257
Documentation Centre 415
DSM 297
DTM 99, 297, 297
Earthquake 359
Enduring Effects 401
Environmental Archaeology 387
ERT 171
Etrusca 225
Excavation 315
Feature Extraction 429
Field Archaeology 3

Flint 219
Fortification 387
Fracture Detection 151
Fuzzy Classification 289
Geo-Archaeology 379
Geographic Information 405
Geographical Information System (GIS) 85, 113, 171, 281, 297, 297, 305, 317, 329, 333, 339, 347, 351, 355, 359, 363, 387, 397, 409
Geophysical 171
Geophysical Survey 121, 191
Geophysics 159, 207
Georadar 125
Glass 419
GPR 135, 139,143, 151,155, 171, 201
GPS 339, 409
Great War 59
Ground Penetrating Radar (GPR) 131
Ground Truth 409
Harappan Civilization 383
Heraclea 31
Hierapolis 11, 159
High Resolution 37, 99, 239,207, 297, 339, 343,425
Historic Air Photos 59
Historical Centre 359
Historical Data 359
Historical-Architectonic Heritage 351
Holographic Imaging 185
Human Occupation 393
Hyperspectral Images 75, 85, 107, 271
ICT 333
IKONOS23, 37, 297
Image Evaluation 85
Image Matching 253
Image Processing Techniques 7, 85
Image Registration 7
In Situ Subsurface Prospecting 131
Induced Polarization 175
Integrated Methodologies 121
Integration 125
Interactive Visualization 243
Internet 405
Interpretation 103
Inverse Scattering 139
Iraq 239, 343
Italy 51
Kassaneva-Devinu 163
Kite Photography 329
K-Means 289
Landscape 103, 121, 247, 373, 387, 397, 401, 405, 425
Landscape Evolution 379
Large Scale Maps 305
Laser Scanning 257, 315
Lidar 99, 103, 107
Lilybaeum 71
Magnetic 125, 169
Magnetic Survey 195
Magnetometry 163
Mapping 317
Measurement 419
Medieval Mound 201
Mesopotamia 379
Metalworking 27
Methodological Dichotomy 47
Microwave Tomography 131, 135, 151
Mines 219
Mining Geology 27
MIVIS Airborne Hyperspectral Sensors 71, 85
Modelling 135
Moisture Detection 185
Monitoring 343
Multi Sensor Studies 383, 409
Multi-Resolution 315
Multi-scale 321
Multispectral 23, 27, 271, 401
Multitemporal 301, 343, 369, 401
Multi-temporal infrared thermography 363
Nasca 297, 429
Near Infrared 225
Near-Surface Survey 179
Neolithic 325
Non Metric Cameras 317

Non-Destructive 185, 329
Non-destructive testing of material decay 363
Norway 285
O.G.S. Crawford 3
Oblique Photos 67
Obsidian 301
Open Source 289
Orthophoto 317, 329
Orthorectification 41, 253
Palaeo-Channels 281, 383
Palaeoclimate 27
Paleopalinology 419
Panoramic Images 317
PCA 11,23
Peru 429
Photo Interpretation 63
Photogrammetry 219, 315, 347
Point Resource (PR) 229
Portus 261
Pottery 419
Prehistoric 369
Processing Techniques 151
Quantitative Analysis 179
Quaternary 281
Quickbird 17, 23, 37, 225, 289
Quick photogrammetry 321
Rabatana 351
Radar 97
Raster classification 363
Reconstruction 369
Remote Sensing 71, 201, 229, 265, 281, 285, 289, 317, 325, 333, 383, 387, 397, 405, 409
Research 51
Resistance 169
Resistivity 163, 219
Restoration 415
Roman Forum 55
Roman Landscapes 37
Roman Ports 121, 261
Sahara 97, 393
Salento Peninsula 63
Sarasvati 383
Satellite 195, 429
Satellite Image 3, 71, 191, 207, 265, 317, 373
Satellite Remote Sensing 11, 305
Scythian Archaeology 275
Sikyon 169
Skills Provision 47
Slag 177
Smelter 177
Software 339
Soil Marks 17
Solar Irradiance 393
South Asia 191
Southern Italy 351
Spectral Index 11
Spectral Signatures 301
SPOT Imagery 195
SRTM 297
St. Philip Martyrium 159
Standard Processing 139
Stereoscopic 41
Subsurface 97
Sub-Surface Geomagnetic Prospection 113
Subsurface Radar 185
Sudan 3
Survey 425
Talakadu Site 7, 409
TDR 143
Template Matching 17
Terrestrial Laser Scanning 113
Thermal 179, 225
Thessaly 325
Tonal Contrast 75
Topographical Survey 113
Topography 97
Turkey 11, 159
Ultralight Plane 225
Ultraviolet 79
Vegetation Indices 23
Veio 125
Velocity Analysis 143, 155

Venetian Lagoon 37
Vertical Photos 67
Via Traiana 67
Virtual Archaeology 239, 247, 257, 261
Virtual Reconstruction 253
Visualization 369
Void Detection 185
Volumetric Water Content 155
Web-Application 247
World Heritage 191, 333

1. Author Index

Aase, S. 285

Abell, L. L 373

Acconcia, V. *125*

Aiazzi, B. 31

Alanyali, F. 351

Albanakis, K. 325

Alena Girelli, V. 313

Alexakis, D. 325

Al-Ganad, I. N.27

Allegrini, A. 71

Allegroni, A. 71

Alparone,L. 31

Amable, G. 401

Angelini, A. 415

Astaras , Th. 325

Avdan, U. 351

Azzam, R. 233

Backe Forsberg , Y. 225

Barba, L. 147

Baronti, S. 31

Bartoloni, G. *125*

Bassani, C. 75

Bavusi, M. 151

Beale, G.C. 261

Bechtel, T. 185

Belgiorno, M. R.419

Benoit, P.27

Bhattacharya, A. 281

Billen, R. 333

Bitelli, G. 313

Blancas, J. 147

Blom, R. 393

Blom, R.G.97

Bogacki, M. 329

Boos, S. 113

Borgioli, G. 185

Bourgeois, J. 143, 275, 59

Bozzi, C.A. 415

Bukovinský, M. 207

Cabuk, A. 351

Cabuk, S.N. 351

Callieri, M.243

Calori, L. 247

Campana, S. 201, 309

Capineri, L. 185

Carrozzo, M. T. 159

Cartocci, A. 301

Cartocci, G. 185

Cassid y, N. J. 135

Castaldo, R. 139

Castrianni, L. 55

Cavalli, R. M. 75

Ceraudo, G. 51

Chiabrando, F. 317

Ciminale, M. 195

Colosi, F. 415

Coluzzi, R. 429

Coningham, R. 191

Coren, F. 107

Cornelis, W. 143

Corns, A. 99

Cottica, D. 37

Creati, N. 107

Crocco, L. 139, 151

Crutchley, S. 103

Cultraro,M. 239

D. Chianese, 167

Dabas, M. 201

Danese, M. 347,363

De Badts, E. 333

De Wulf, A. 253, 275

Dellepiane, M. 243

Delli Santi, M. 355

Deroin, J.-P. 27

Deveci, A. 351

Devereux, B.401

Devriendt, D. 253

Di Fiore, B. 167

Di Giacomo, G.P. 41, 339

Ditaranto, I. 41

Drzewiecki, M. 3

Due Trier, Ø. 17

Dvornikov, E. P. 275

Earl, G.P. 261

Eisenbeiss, H. 297

Eppelbaum, L. V. 181

Ergincan, F. 351

Esbensen, K.285

Falorni, P.85

Fangi, G. 415, 289

Farr, T.G. 97, 393

Fedi, M.139

Ferrari, I. 257

Ferrari, V. 67

Feynman, J.393

Florsch , N. 175

Forte, M. 247

Fozzati, L. 37

Fux, P. 297

Gabellone, F. 241, 257

Gabrielli, R. 415

Galiberti, A. 219

Gallo, D. 195

Gallotti, R. 301

Ganovelli, F. 243

Garbuzov, G. 397, 405

Garcia-Moreno, R. 333

Garofalo, B. 139

Gheyle, W. 275

Ghorbani, A. 175

Giardino, M. J. 271

Giuri, F. 257

Gizzi, F.T. 359

Gläßer, C. 369

Goossens, R. 253, 275

Gourley, B. 169

Grøn, O.285

Guglietta, D. 71

Hanson, W.S.47

Heckes, J.27

Heyvaert, V.M.A. 379

Holmgren, R. 225

Hornung, S.113

Ivashov, S. 185

Jianzhong, S.229

Jung, P.113

Kamh, G. M. E.233

Kamini, J.409

Keay, S. 121, 261

Kortenaar, S.T. 125

Kozciak, S. 301

Krishna Murthy, M.S. 409

Kucheryavski, S. 285

Lacicerchia G. 93

Lanorte, A. 225

Lasaponara, R. 11, 31, 195, 213, 225,429

Lazzari, M. 347

Lentini, A. 419

Leti Messina, T. 321

Leucci, G. 159, 155

Ligorred, J. 147

Limoncelli, M. 257

Llubes, M. 175

Lolos, Y. 169

Loska, A. 17

Malinverni, E. S. 289

Małkowski, W. 329

Mantovani, F. 219

Marasco, L. 201

Marcolongo, A. 321

Martino, F.M.219

Măruia, L. 387

Masini, N, 11, 31, 195, 213, 225, 347, 359, 429

Merola, P.71

Micle, D.387

Milillo G. 93

Misiewicz, K. 329

Müller, H.113

Negri, S. 155, 159, 313

Nuttens, T. 253

Nuzzo, L. 135, 159

Oikonomidis, D. 325

Oltean, I. A 373

Orazi, R. 415

Orefici, G. 213, 429

Orlando, L. 131

Orlando, P. 285

Ortiz, A. 147

Øyen Larsen, S. 17

Paillou, P. 97, 393

Palmér, S.285

Paradiso, M. 185

Pascucci, S. 75
Patra, S.K. 7, 265
Pavelka, K. 207
Persico, R. 139
Pescarin, S. 247
Pietrapertosa, C. 107
Pignatti, S. 75
Piperno, M. 301
Piro, S. 125, 201
Piscitelli, S. 151
Plyson, A. 143
Potenza, M.R. 359
Pozzi, A. 321
Pringle, J.K. 135
Prisco, G. 151
Raczkowski, W. 3
Rajawat, A.S. 383, 409
Rao, S.409
Remondino, F. 309
Richter, C.293
Richter, T. 369
Rizzo, E.213
Roblet, P. 175
Ruzmaikin, A. 393
Salonia, P. 321
Salvi, M. C. 301
Salvini, R. 219, 301
Sammarco, M. 63
Sampietri, S. 71
Sanseverino, D. 363
Sarris, A. 169, 325
Sauerbier, M. 297
Scardozzi , G. 241
Scardozzi , G. 11, 41, 305, 339, 347, 425
Scheuer , S.369
Schmidt, A.191
Scolastico, S. 321
Scopino, R. 243
Shaw, R. 99
Simpson, D. 143
Solberg, R. 17
Soldovieri, F. 131, 139, 151
Sordini, M. 309
Spanò, A. 305, 317
Stargardt, J. 401
Sterzai, P. 107
Stichelbaut, B. 59
Strutt, K. 121
Stylegar, F.A. 285
Svatušková, J. 207
T. M. Millington, 135
Tarantini, M. 219
Teichert, B. 293
Téreygeol, F. 27, 175
Thürkow, D. 369
Tigny , V. 333
Tolochko, I. 397
Török-Oance, M. 387
Traviglia, A. 23, 37, 85
Tytgat, C. 253
Vallianatos, F. 151
Van Damme, D. 253
Van Ruymbeke, M. 333
Vellico, M. 107
Verdonck, L.143
Verhoeven, G. 79
Verkinderen, P. 379
Verma, M. 265
Vespe, F. 93
Vittuari, L. 313
Walstra, J. 379
Zamuner, D.201
Zhuravlev, A. 185

SCIENTIFIC–DISCIPLINARY AREAS

Area 01 – Mathematical and Computer Sciences

Area 02 – Physical Sciences

Area 03 – Chemical Sciences

Area 04 – Earth's Sciences

Area 05 – Biological Sciences

Area 06 – Medical Sciences

Area 07 – Agricultural and Veterinary Sciences

Area 08 – Civil Engineering and Architecture

Area 09 – Industrial and Information Engineering

Area 10 – Antiquity, Philological–Literary and Historical–Artistic Sciences

Area 11 – Historical, Philosophical, Pedagogical and Psychological Sciences

Area 12 – Juridical Sciences

Area 13 – Economic and Statistical Sciences

Area 14 – Political and Social Sciences

Aracne Publishing's publications are on

www.aracneeditrice.it

Printed in September 2008
by « Braille Gamma S.r.l. » of Santa Rufina di Cittaducale (Ri)
for « Aracne editrice S.r.l. » of Rome

PAPERS: Cover: *Patinata opaca Bravomatt plastificata opaca* 300 g/m², Inside: *Patinata opaca Bravomatt* 115 g/m².
PREPARATION: Thread binding / paperback.

Printed in collaboration with Finsol S.r.l. on technology Canon Image Press.